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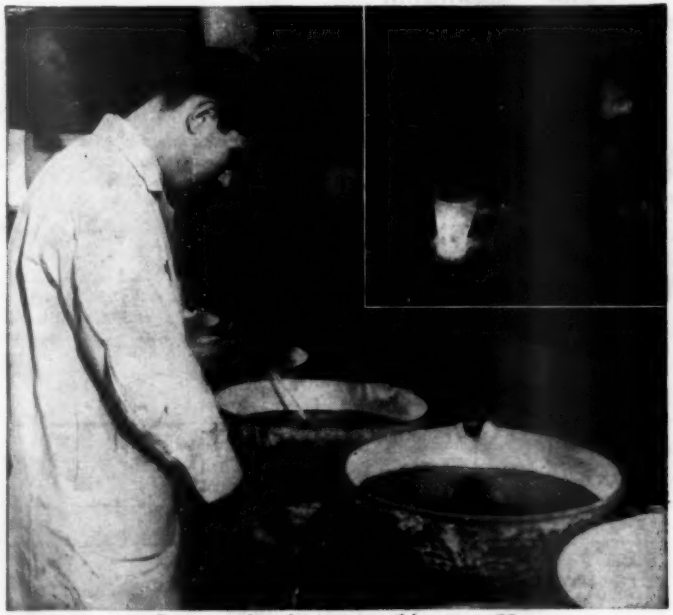

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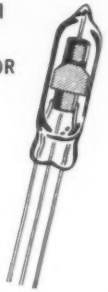

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NUCLEONICS

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The Atomic Industry and Human Ecology

VI—ON UNCERTAINTY

THE PRINCIPLE OF UNCERTAINTY in physics occupies a place of honor comparable with that occupied by Einstein's famous $E = mc^2$ formula. Nobel prize winner Heisenberg was the first to recognize the fact that uncertainty or indeterminacy enters as a matter of essential principle when trying to specify the motions of electrons with precision, and although (as with many first formulations of principles) it has been subject to criticism from time to time, the fundamental truth is now universally recognized and extended to other elementary particles as well.

The practical man may be reminded that wave and quantum mechanics were based (in part) on the uncertainty principle, and that these essentially mathematical disciplines were useful in investigations leading to nuclear fission and the atomic bomb. It is not too extraordinary that a purely mental construct, uncertainty, should have assisted in such a result—almost all of the practical engineering and productivity of this century may be traced in detail to similar beginnings. The extraordinary thing is that any one end result should be associated with and not infrequently blamed for the great "uncertainty" in human ecology that has followed announcement of the bomb. One must place even nuclear fission in context with the rest of living; one must strive for basic understanding.

General Eisenhower and Dr. Bush have taken immense strides forward within the recent past in accomplishing a foundation on which this structure of understanding may be built. Eisenhower's speeches on security clearly show the outline of a long-needed *principle of uncertainty in the social sciences*, a recognition of the essential indeterminacy in human affairs not unlike that existing in every effort to determine position and velocity of an electron simultaneously and accurately, say, whether or not man will ever accept such a simple statement notwithstanding. Bush is at his best in beginning to clothe the framework with facts concerning modern arms of all sorts, at least with such facts as may be discussed publicly, but he has also recognized the fundamental principle in considering the unpleasant possibility of "a people fawning for handouts on an intriguing bureaucracy."

Fortunately, these (and other) men have begun to point the pure light of reason on the false notion that security by concealment or legislation is possible. The best security is and has always been obtained by accomplishment. The proponent of status quo may seem to lead, but by his very nature cannot

maintain the position. Rather, as stated by General Cates of the Marine Corps, NUCLEONICS believes "a statutory safeguard . . . is not a refuge at all but a battle position which must be defended in full force."

These facts are not palatable to many. With all its good for mankind, civilization is difficult. Civilization is especially difficult when the people have lost their mobility. One might argue in fact that civilization may prove to be too difficult unless man retains or regains a measure of mobility. Not too many years ago in the United States the solution was at hand for any able bodied man with the spirit of adventure for, equipped with little more than a rifle and knife, he could strike for the frontier and opportunity. The day of such physical mobility for large numbers of the people is over (unless and until someone succeeds in founding a colony on some planet similar in physical characteristics to the earth); but the day of mobility through education has scarcely begun.

There has been an unfortunate tendency to foster the immediate desire of students to learn only techniques and applications so that, at the end of a prescribed course of study, each one who successfully completes a series of examinations can step into a job at big wages. The desire for such immediate success is understandable, especially in a civilization that recognizes citizenship only after several years of physical manhood. Moreover, in an expanding economy, industry has often exerted pressure on those who teach to prepare students to follow some narrow field of knowledge. It must be recognized now, however, and it is of course recognized by many, that the man who lays down his books at the end of his college days never to resume the labor of learning is but one more individual whose essential mobility is nil.

These things have made the atomic industry essentially a young man's industry. Not that quanta, cross sections, and fission are difficult to understand. Not that greater physical exertion or quicker responses are required to use a slide rule in nuclear physics than in electrical power distribution, say; but simply that only those who attended (or gave) formal lectures or obtained equivalent instruction elsewhere after 1939 ever learned the newer aspects of science. The thesis of this piece is that ever more and more men must study fundamentals, maintain their knowledge up to date in broad areas, and thoroughly prepare for mobility in outlook and occupation.

This course of action will decrease the time and money wasted in almost ceaseless effort to "breathe down the neck" of one who has been assigned a task, will stop the witch hunting now begun even against minors, and hasten the day of a true National Science Foundation in the United States—one in which all the sciences are sponsored, particularly the psychology and social psychology we need so badly. This course of action will, finally, prepare man to recognize the principle of uncertainty that exists in daily living, without fear and without lost effort. He will alarm less easily and scorn the current fetish in public statements and headlines to frighten, contradict, and accuse.

Note: The preceding editorials in this series devoted to the subject of "The Atomic Industry and Human Ecology" were entitled: I—Waste Disposal (August, 1949); II—On Risk (September, 1949); III—On Getting the Word (October, 1949); IV—Relax (November, 1949); V—The Air We Live In (December, 1949).

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THE NATIONAL LABORATORIES—

Their Role in Atomic Energy Development*

By HENRY D. SMYTH

Member

United States Atomic Energy Commission

Washington, D. C.

IN THE PERIOD between the two World Wars, science flourished in this country to a greater degree than ever before. Although we continued to depend heavily on Europe, particularly in such fields as theoretical physics, the number of well-trained, able men in this country multiplied greatly and our laboratories became well-equipped and well-organized. The value of research began to be recognized although not completely understood.

Reasons for Research

There are two major reasons why scientific research contributes to the vigor and welfare of a people. The first is that it enlarges and enriches men's minds. It gives them a better balanced picture of the universe in which they live and of their place in it. It stimulates their imaginations; it strengthens their intellectual powers; it gives them confidence and tools with which to attack collectively some of the problems which confront them.

The second reason for pursuing scientific research is the contribution that it makes to our material welfare. Though the actual material results of research are the major justification for the existence of many of our great scientific enterprises, and particularly those of the Atomic Energy Commission, it has become clear that we cannot separate one kind of research from the other.

In this paper, research aimed primarily at the fundamental laws of nature is referred to as basic research, and research aimed primarily at material results is referred to as applied research.

Before World War II there were four kinds of organizations pursuing, with varying emphasis, either or both of these aims. These were, of course, first, university laboratories; second, industrial laboratories; third, independent research institutions; and fourth, Government laboratories. All these types of institutions still exist. One can roughly say that the university laboratories and the privately endowed research institutes are primarily con-

* Based on a talk given at the General Information Meeting banquet, Oak Ridge, Tennessee, October 25, 1949.

The author of the famous "Smyth Report"—now an AEC commissioner—describes the nature of science in terms of three functions: basic research, applied research and teaching. He shows the need for the national laboratories, and how each laboratory must serve at least two of the above functions.

cerned with basic research, while the Government laboratories and industrial laboratories are more concerned with applied work. However, one must remember that the functions of all of them overlap both fields. In the case of the universities, there is a third function, that of teaching, so that even university departments doing no applied work have more than one objective.

It is thought by some that the ideal place to do scientific research is in an institute devoted solely to that end. However, it may be said that most of us can do better basic research in an organization that is not devoted exclusively to basic research. In the scientific departments of the universities, this other objective is teaching, which has the additional advantage of bringing men constantly in contact with fresh, young minds. In Government and industrial laboratories, the contact with specific applied problems and with the men who have to get the answers to such problems provides a similar stimulus.

Increased Cost of Research

Another factor that should be mentioned at this point is the influence of the greatly increased cost of research on the relative importance of Government and industrial laboratories compared to those in universities and privately endowed institutes. The importance of major equipment of very great cost has grown steadily for the past twenty years, particularly in the field of experimental nuclear physics. It is easy to overemphasize the importance of the equipment compared to brains—and in this country we have a tendency to do just that—nevertheless, apparatus such as reactors, Van de Graaffs, and cyclotrons is important, and research in this country, at least in physics, might have taken a very different course since the war had not nuclear physics demonstrated its value in military affairs so that large expenditures of Government money for elaborate equipment could be justified.

AEC Objectives

The foregoing is in introduction to a discussion of the reasons why the national laboratories are supported by the Atomic Energy Commission. The AEC has three principal objectives:

1. To make more and better weapons
2. To develop possible peacetime uses of atomic energy
3. To develop such scientific strength in the country as is needed in the long run to support the other two

Success in each of these three objectives requires activity in terms of all three of the functions necessary for a flourishing science, namely, basic research, applied research, and teaching.

In amplification of this point, take first the production of more and better weapons. Here teaching would seem

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to be of little importance. Perhaps so. Yet anyone who has been at Sandia and Los Alamos knows that its need exists. As to research, most of it is necessarily applied in character, yet it would be folly to forget that the atomic bomb of 1945 was the direct result of basic research carried on in the 1930's with no thought of any practical application.

Evidently when we know as little as we do of nuclear forces and even of the experimental values of certain nuclear cross sections, we must study these basic problems. For nuclear explosives, we need more knowledge of nuclear laws and constants. Similarly for the other components of the weapons and for the many associated processes of production, we need more basic knowledge of the chemical and physical properties of materials. Surely the weapons of ten years from now will depend on the research of today.

The second objective of the AEC, peacetime uses of atomic energy, likewise involves applied research, basic research, and teaching. Here, the relative emphasis on function does not appear to shift very much compared to that of the weapons program. In subject matter, it certainly does shift with greater weight going to medicine and biology compared to the engineering and physical sciences.

Finally, to achieve the third objective of the AEC, building up the scientific strength of the country, we still need all three of our functions, basic research, applied research, and teaching, but there certainly must be an increased emphasis on teaching; therefore, the universities must play a larger part in achieving this objective than the other two. The AEC plays a direct role here, too.

The national laboratories help toward all three of the objectives of the AEC, as do other laboratories throughout the Nation. There are good reasons why the national laboratories are needed and why their functions cannot be discharged by already existing research or development organizations. One of these, of course, is secrecy. Another reason is our wartime experience which showed the advantage of gathering together a large group of men from the various divisions of science to work in close cooperation on problems involving a variety of fields and techniques.

Such a group needs to be larger and more varied than can healthily be built up in any single university. Furthermore, it must be ready to take orders. There are times when the AEC must have answers to perfectly definite practical questions on which the safety of the country depends. Sometimes getting the answers to such questions involves long arduous programmatic work that may be both dull and dangerous. Such work cannot be done properly or effectively in university or industrial laboratories.

Finally, the nature and cost of the special equipment required for much of both the basic and applied work of interest to the AEC is such as to dictate its location in Government-supported laboratories. The financial quanta involved in this enterprise are way beyond the absorption limits of university budgets or, indeed, of those of single industrial corporations.

Historical Background

Of the group of the five big laboratories—Oak Ridge, Argonne, Brookhaven, Berkeley and Los Alamos*—Berkeley is the only one which had a prewar history. It was well established in the thirties as the largest single university installation for nuclear physics. During the war, it was diverted to isotope separation after the construction of the 184-inch cyclotron had

* Berkeley and Los Alamos are not national laboratories by title. They are included in this discussion because of their position in the atomic energy field.

begun and before it was finished. After the war, it seemed natural to continue it, first out of Manhattan District funds and then with funds from the AEC, as a research center for nuclear physics and radiochemistry. Because of its history, it naturally continues as sort of a cross between an enlarged university department and a localized AEC installation. Essentially its support is a recognition of the existence of an able group of scientific men with interests and equipment closely allied to the central interests of the AEC and, therefore, well worth support by AEC funds. As long as the situation continues as healthy as it is there, AEC control should be relatively weak.

At the other extreme is Los Alamos which was set up during the war for a specific purpose and still exists for a specific purpose. This does not mean that no basic research should be done at Los Alamos. As explained earlier, a certain amount of basic research is entirely appropriate there. Yet, most of the work is not only applied but is programmatic. In a sense, the people running Los Alamos have the simplest problem of any of the AEC laboratories, because they have the clearest and most immediate objective.

The Argonne Laboratory in Chicago also grew out of a war laboratory which had been set up there for a specific purpose, first, to achieve a chain reaction and then to design the Hanford plant for the production of plutonium. It was the first reactor laboratory, but such was the variety of the problems it had to study that only a small group of the men there were directly concerned with reactors. The reconstruction of Argonne on a new site, and the assignment of the principal responsibility for reactor development seems to have caused more of a discontinuity in the purposes and functions of that laboratory than at say either the Berkeley or the Los Alamos laboratory.

The laboratory at Oak Ridge started as a service and research laboratory in connection with the first chain-reacting pile. Its original functions came directly out of that activity, and it was here that the first considerable amount of plutonium was produced. Many of those functions have now lapsed for one reason or another, yet such is the vitality of the group that it has established itself as an essential part of the AEC program.

Oak Ridge always has been partly a production center, and it still has the function of isotope manufacture and of making other materials essential to the work of the AEC. Also, it still has a number of testing functions for which it is well equipped and in doing which, it performs an extremely valuable service. Biological research has built up largely since the war until it is very effective. It can probably be said that Oak Ridge National Laboratory does a lot of miscellaneous jobs on development and research which are essential to the AEC and which do not have to fit neatly into an organization chart or research program to justify their continuance.

Finally, Brookhaven Laboratory is the only national laboratory founded since the war and naturally has a very different origin from the others. It really owes its existence to the recognition on the part of a number of people in the Northeast that there were certain facilities which no one university could afford to construct but which were badly needed if the research departments of these universities were to continue first rate. This, of course, is no justification for spending a lot of Government money at Brookhaven.

The other side of the picture was the recognition first by the Manhattan District and later by the AEC that there was a large group of able scientific people in the northeastern area who, in the long run, could contribute

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MAJOR RESEARCH CENTERS OF THE AEC . . .

Ames Laboratory, Ames, Iowa

This laboratory is operated by Iowa State College under contract with the AEC. The principal objectives of the Ames program are fundamental research and development work essential to new developments in peacetime applications, as well as weapons. As an additional function, the Ames Laboratory performs a great many services in the production of special materials for the atomic energy program, with the work done by highly trained scientists. Also, the laboratory has been effective in training scientific personnel.

Knolls Atomic Power Laboratory, Schenectady, N. Y.

This laboratory is especially concerned with power and breeding applications and has been operated for the Atomic Energy Commission by the research laboratory of the General Electric Co. since 1946. Scientific groups from various industrial organizations participate in the research work of the laboratory. In addition to chemical, physical, metallurgical, and chemical engineering laboratories, a reactor for the experimental production of atomic power and as a possible breeder will be constructed. The completed facilities will also include a hot chemistry laboratory.

Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.

Operating under contract with the AEC, the institute is comprised of 24 southern universities which have incorporated to encourage atomic energy research, training, and education, particularly in the South. The institute conducts a radioisotope training program, a resident graduate program, which enables Oak Ridge employees to continue their education, a graduate training program through which students for the doctoral degree in the sciences from any recognized university may carry out their research in Oak Ridge laboratories, and a research participation program in which university faculty members may use the research facilities at Oak Ridge.

greatly to the basic scientific problems facing the AEC and were, therefore, worth supporting.

Because of its origin, and because the hope is that the staff at Brookhaven will be largely a rotating staff, emphasis there should be principally on basic research. It is still uncertain just how it will work out, but it would seem that the "bread-and-butter" routine work of the Brookhaven group is teaching at the various universities in the area rather than doing programmatic work at Brookhaven, although it is expected that, as facilities are built up there, some programmatic work will be done and the people there will be glad to have it. As far as teaching at Brookhaven itself is concerned, it does not seem that that is going to be very important at Brookhaven, although there are others who take a different view. At Oak Ridge, on the other hand, the teaching, in a general sense at least, should be very valuable because of the relative weakness of the scientific departments of universities in this region.

There is one aspect of the teaching function of all the national laboratories that arises directly from our present

. . . Other Than National Laboratories

The institute also operates the American Museum of Atomic Energy and is now developing a program for the study of the treatment of malignant diseases and the training of medical personnel in new techniques which may be developed. This program will not be open to general patients.

Rochester Atomic Energy Project, Rochester, N. Y.

This laboratory, operated by Rochester University under contract with the AEC, was organized in 1943 to investigate medical and biological problems arising in connection with the atomic energy program. In addition to research studies the laboratory performs many service functions for other laboratories and industries engaged in atomic energy activities.

Westinghouse Electric Co., Atomic Power Division, Pittsburgh, Pa.

Located on the site of the old Bettis Airport near Pittsburgh, Pa., this laboratory is now under construction, with completion expected this year. Research and development work to be carried on here by the Atomic Power Division of the Westinghouse Electric Co., will be directed at the specific application of nuclear energy to the propulsion of naval vessels. Work is now being carried on at the Bettis site and in other parts of the Westinghouse Co.

Y-12 Research Laboratory, Oak Ridge, Tenn.

This laboratory operates in connection with the Y-12 electromagnetic separation plant constructed during the war to produce uranium-235. Today, under contract with the Carbide and Carbon Chemicals Corporation, the plant produces stable isotopes of many other elements which are distributed to institutions throughout the Nation for research in biological and physical sciences. A program of research on electromagnetic and other methods of isotope separation is also conducted. This research group is being consolidated with the Oak Ridge National Laboratory.

policy of secrecy. There are special courses and special meetings devoted to classified material. These are certainly most appropriately carried out in the national laboratories. But these activities, however valuable, should not be cited as reasons for the existence of the national laboratories because it should not be implied that our present secrecy policy will never be modified.

Laboratory-Washington Relations

In the operation of the national laboratories and in the carrying out of its program, the AEC in Washington delegates a large part of its authority to offices in the field. This has a great many advantages. It seems, however, that it does raise some difficulties in connection with the laboratories. These difficulties are not fundamental. More maturity in the whole arrangement will eliminate them.

It is evident that the regional offices have a great variety of responsibilities, including housing, budget, research program, *etc.* They cannot be expected to see the picture as a whole, and it is particularly difficult for them to make

(*Continued on page 67*)

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ENGINEERING ASPECTS OF NUCLEAR REACTORS—II

In this second of four articles, the author continues his discussion of the basic components of the pile. He describes the various methods for controlling the operating level of the reactor, and the problems involved in removing the heat developed. Existing installations are cited as examples.

By L. A. OHLINGER

Northrop Aircraft, Inc., Northrop Field
Hawthorne, California

THE COMPLEX NATURE of nuclear reactors results, in no small part, from the design of the components of the reactor. In this article, we will expand on the discussion started last month of the problems involved in the design of the reflector, the radiation shield and the control system.

The Reflector

In an operating pile, it is inevitable that some of the neutrons diffusing through the pile will emerge through the outer surface of the reactor and be lost from the chain reaction. For the most efficient propagation of the chain reaction, we must retain as many neutrons as possible at the end of each generation for every neutron that began the cycle. Therefore, it is advantageous to prevent the escape of these neutrons that would otherwise leak out of the pile. This can be done by surrounding the reactor with a blanket of material—the reflector—that will scatter or reflect as many as possible of these neutrons back into the pile without absorbing too many in parasitic capture.

Good scattering characteristics and a low probability of neutron capture are the same requirements as for a good moderator. Hence, the same materials that are suitable as moderators are suitable as reflectors; and, while the moderator and the reflector in a particular pile may be of two dissimilar materials, there is no reason why the reflector cannot be simply an extension of the moderator beyond the active section of the pile with no fissionable material contained therein. The thickness of the reflector depends upon the properties of the material used, but its efficiency decreases rapidly with increasing thickness so that there is little extra saving in using very thick reflectors.

One important fact should be noted about the use of a reflector—a good reflector decreases the size of the active section of a pile and the amount of nuclear fuel required, but it does not decrease the over-all size of the unit. A combined pile and reflector are larger than the corresponding pile without a reflector.

Shielding Materials

The basic characteristics for a radiation shield* around a nuclear chain reactor are (1) a good moderating material, preferably a light element to avoid the secondary gamma production from inelastic scattering, (2) a good neutron absorber, preferably boron to

* EDITORS NOTE: For a more complete discussion of radiation shielding, see "Shielding from Nuclear Radiations" by the same author in NUCLEONICS **5**, No. 4, 4 (1949).

avoid the secondary gamma production from the absorption of neutrons by an (n,γ) process, and (3) a dense, heavy material for attenuating the gamma radiation.

No one material answers all these requirements, except when it is used in large quantities. Therefore, practically all radiation shields are a homogeneous or heterogeneous arrangement of two or more components, each having the characteristics necessary to perform one of the above functions. Since boron is a light element and answers both of the first two requirements, it is pretty sure to be a component in most radiation shields. The choice of the balance of the components depends upon the amount of weight that can be allocated to the shielding.

In mobile power plants, such heavy materials as tungsten or tantalum might find useful application in their elemental form or in combination with the boron or other moderating materials. For example, a carbide of these materials might be used because carbon is a relatively good scatterer and has such a low probability of neutron absorption that the secondary gamma production is relatively small. In particular, for high temperature piles, the refractory nature of a metallic carbide is very useful for a shield. However, the presence of the heavy element as a gamma attenuator inevitably results in the production of some secondary gammas because of the inelastic scattering of neutrons that is introduced thereby.

There are other shielding materials, both heavy and light, that might prove more effective for shields around mobile power plants, but much research and development is required with them to produce the optimum shield having all the necessary characteristics. In stationary piles, the total weight of shielding is not as significant a factor, so that more conventional and less expensive shielding materials can be employed. Even ordinary water can be used as a shield if enough feet of it are employed. Concrete is another inexpensive shield that requires only about half the thickness of shielding required by water. By peppering the water or concrete shield liberally and homogeneously with small units of other suitable materials (*e.g.*, iron), the thickness can be further reduced from that required by the plain water or concrete alone. The hydrogen in water or concrete is an excellent moderator because of its low atomic weight and high capture cross section so that hydrogenous materials make good shielding materials except for the secondary gamma production from the (n,γ) reaction in hydrogen.

The earlier shields were usually concrete whereas the later shields were sometimes composed of alternate layers of different suitable materials.

Cooling the Shield

The moderation and attenuation of the neutron and gamma radiation from a pile results in the production of what may be an appreciable amount of heat within the shield. Since the radiation attenuation is largely exponential, the largest portion of this heat is released in the first few inches of the shielding next to the pile. Accordingly, shields can be deliberately fabricated in two separate sections, a section next to the pile for absorbing most of the heat produced within the shield, and the larger shielding section beyond the heat-absorbing shield for absorbing the balance of the hazardous radiation. Special cooling can then be provided for removing the heat from the inner shield while the outer shield dissipated its small amount of heat by thermal radiation. This arrangement is no longer looked upon with much favor, because it usually results in a large secondary gamma production.

Since the neutron radiation stopped by a shield may result in some decom-

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position of the shield components, it may be necessary to provide means for removing the products of decomposition at intervals. Liquid components in the shields provide the simplest means of carrying away the heat as well as the products of decomposition because they can be recirculated through the shield at rates compatible with the amount of heat to be removed from each section of the shield. Since water is an inexpensive and plentiful hydrogenous material, it constitutes a good potential shielding material for stationary piles. Likewise, it will dissolve reasonable quantities of boron compounds to provide the necessary boron so desirable in a shield. The heavy element in the shield can be furnished by graded shot of a material like steel.

Partial Shielding

In mobile nuclear powered plants, some slight saving in the total weight of shielding can be achieved by judicious arrangement of the pile and its shield relative to the personnel and equipment to be protected. Since the flux varies inversely as the square of the distance of separation between the radiation source and the observer, the farther away the observer and the equipment are from the pile, the greater is the attenuation due to distance and the less the additional attenuation that must be supplied by the radiation shield.

Another possible means of saving a fraction of the total shielding weight is by surrounding the reactor with shielding of nonuniform thickness, arranged so that the shield on the side facing the observer, together with the separation distance, provides complete attenuation down to the allowable radiation dose level. The balance of the shielding would be thinner on the sides and still thinner on the face away from the observer because radiation through these faces will not reach the observer directly, but only by subsequent scattering from the air or other surrounding medium. Since the observer sits in the shadow of protection of the completely opaque shield on the near side, this type of shielding is frequently called "shadow" shielding.

The Controls

Since the energy released in a pile is the result of fission, the amount of energy released at the operating power level of the pile depends upon the number of fission processes occurring throughout the pile in a unit of time. This in turn depends upon the neutron density throughout the pile. The operating level of a pile can be controlled by controlling the neutron density.

The reproduction factor k is the ratio of the number of neutrons at the end of a single generation to the number at the beginning of that generation. And the number of neutrons surviving one cycle depends upon the relative number of neutrons escaping from the pile, being absorbed in parasitic capture, or being absorbed in fission. Therefore, it is obvious that we can control the reproduction factor, and hence the neutron density, by changing the leakage, the amount of absorption by parasitic capture, or the amount of fissionable material for absorbing the neutrons.

The first of these involves moving or changing any component that minimizes the number of neutrons leaking out of a pile. The reflector (Fig. 1*a*), if any is used, is one such component. The surface-to-volume ratio is another factor. In the latter case, a relative motion of pile sections (Fig. 1*b*) could effect a change in geometric configuration and expose more or less surface for the same volume.

Another method of controlling the pile by changing the neutron leakage from the pile when there is no reflector is by changing the amount of moderator in the pile (Fig. 1*c*). This not only controls by changing the physical volume

of the reactor but also by changing the relative proportion of the leakage factors for the escape of neutrons while they are slowing down and after they have reached thermal energies.

To control a reactor by changing the amount of fissionable material in a pile, the nuclear fuel must be arranged so that it is readily removable (Fig. 1*d*) and replaceable in increments suitable for controlling the pile.

While the above methods are better suited and, in some cases, the only methods by which small piles can be controlled, thermal piles and low-energy intermediate piles are usually more easily controlled by changing the amount of absorber in a pile. This not only affects the diffusion lengths and the thermal utilization (fraction of thermal neutrons absorbed by the fuel), but it also changes the relative distribution of the neutron density throughout the pile.

Absorbing controls may be introduced into the pile in several different forms, but all of these must be made from a material having a very high cross section for the absorption of neutrons. Typical examples of these are boron and cadmium or their compounds. They may be introduced into the pile or into the reflector or both depending on the type and design of reactor.

Since absorbing controls operate by robbing the chain reaction of large quantities of neutrons, the relatively large neutron absorption within the control mechanism results in a large heat release in the controlling medium, and this must usually be removed by special cooling provisions. Likewise, highly centralized absorbing controls are not nearly as effective as more homogeneously distributed controls.

Three Types of Controls

Since the operation of most types of piles except the low-power research

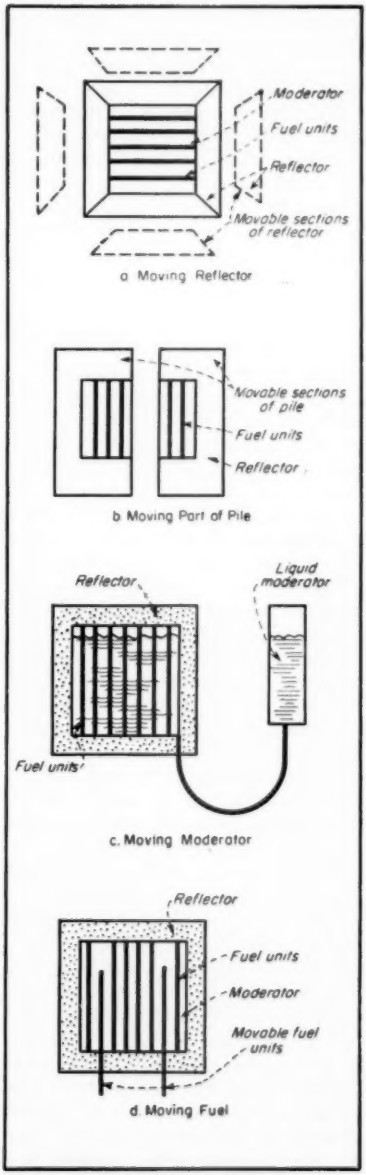

FIG. 1. Control methods

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tools, is at power levels of hundreds or thousands of kilowatts, a coarse or large increment type of control is required for bringing a pile up to power level, shutting it down, and making large changes in the operating level of the pile. Once a pile has been brought up to approximately the desired operating level, a fine or regulating type of control is required for making the small adjustments necessary to establish and maintain the exact operating level over long periods of time.

Since no mechanism is perfect and there are many potential hazards in a nuclear reactor and its accompanying power plant, it is obvious that there must be a third type of control designed for emergencies. This so-called safety control must be capable of stopping the nuclear chain reaction, under even the most adverse conditions, within a period of time that will prevent self-destruction of the pile or any major change in that direction. Likewise, this safety control must operate to prevent any pile activity that would result in a flux of radiation from the shielding greater than that considered safe for normal and emergency operation. Whereas the coarse and fine controls are mechanisms that must operate within a period of something in the neighborhood of 5 to 10 seconds, the safety controls must be devices that function with such speed and assured mechanical perfection that the pile control will become effective within one or two seconds.

Since the coarse and fine controls operate to change the reproduction factor by entirely different increments, it is not easy, although not impossible, to combine these two functions into one set of controls. Likewise, since the coarse and fine controls normally operate at a speed much slower than that of the safety controls, it is not always feasible, though not impossible, to combine the functions of the safety control and either or both of the other controls into one piece of mechanism that will operate at such varying speeds. Therefore, pile controls generally consist of two or three different systems having different operating and absorbing characteristics, and only rarely can the designer achieve a single control system that will be completely reliable under all conditions. As a matter of fact, in some of the existing piles, there are not only three but four separate sets of controls in which the fourth set is used as a super-safety control to operate in the event of any failure of the regular safety control to function properly.

Removing the Energy

The energy that is released in fission manifests itself in the pile as heat which must be removed to successfully operate the pile continuously. Whether the heat that is removed is to be dissipated as a waste product or is to be utilized for practical purposes as heat or power, the methods of removing it from the pile follow the same general principles, even though the techniques may be quite dissimilar. Since the effect of removing the heat from the pile for any purpose is to keep the pile from overheating, this process of heat removal is often referred to as cooling the pile, despite the operating temperature of the pile.

In its simplest conception, the heat produced within the nuclear fuel may be transferred to the moderator and diffused through it to the surface of the pile from which it would then be dissipated by radiating thermally. Since the surface-to-volume ratio of a pile is purposely kept small in order to reduce the neutron leakage, it is obvious that not much energy can be dissipated in this manner, even from a very hot pile. Therefore, piles of this type must be operated at very low power levels, as, for example, in research units.

A second method of removing the energy from a pile is one applicable

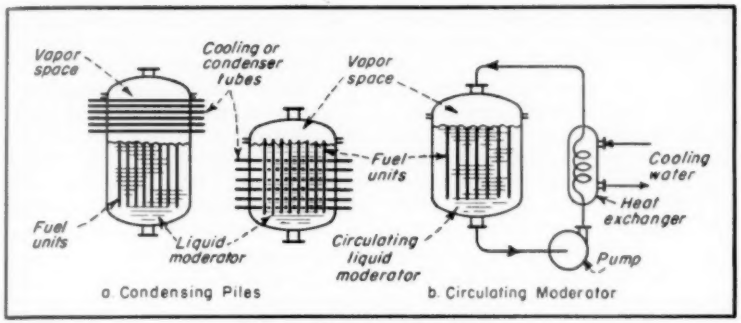

FIG. 2. Removing the energy

only to those having liquid moderators In this case, the moderator is either allowed to boil and recondense (Fig. 2*a*), or allowed to circulate outside the reactor for cooling by conventional means (Fig. 2*b*). In the former case, the moderator may be boiled off to form vapors suitable for operating a power plant, in which case the moderator must be constantly replaced, or it may be vaporized and recondensed on cooling tubes within the body of the reactor or within the vapor space immediately above the moderator. While this appears to be a simple and excellent method of obtaining high rates of heat transfer, the irregular variations in the average density of the coolant due to the bubble formation may wreak such havoc in the nuclear characteristics of the pile that control will be virtually impossible.

The second arrangement suggested, that of circulating the moderator, has actually been used in one of the piles at the Argonne National Laboratory. There, the moderator is heavy water, which absorbs heat from the fissionable material in the pile and is then recirculated through a heat exchanger where it is cooled and pumped back into the pile for further heating. Except at extremely high pressures sufficient to suppress the formation of bubbles in the reactor, this arrangement is not practical for the production of high specific power (power per unit weight of the nuclear fuel).

Moving the Fuel

Another means for removing the energy from the pile is to remove the fissionable material from the pile for cooling and replace it for further heating in a continuous or intermittent recycling arrangement. If the fissionable material is in solid form, such a scheme entails no small amount of ingenuity in solving the mechanical problems involved. Many strange and wonderful schemes have been proposed for cooling the pile by this method, including rolling balls, moving chains or tapes, rotating disks or wheels, and reciprocating rods. In each case, the portion of the fuel in the pile heats itself while in the pile and gives up its heat to a cooling medium during its portion of the cycle outside the reactor. A simpler method of moving the nuclear fuel is to utilize a liquid compound or a solution or slurry of the fuel in a liquid carrier. Examples of this are the liquid, uranium hexafluoride (UF_6), or solutions of uranyl nitrate or sulfate in water.

Obviously, the carrier fluid for the solution or suspension might also serve as the moderator and be circulated out-

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side the reactor with the nuclear fuel in order to remove the energy produced in the pile. In all of the methods for heat removal by moving the fuel, the major objections are the large inventory of fissionable material held up outside the reactor, the mechanical problems, and the dangers of radioactive hazards outside the pile proper. Specifically, the radioactivity in the fuel and its fission products will contaminate the entire recirculating system inside and outside of the reactor so that all of this system has to be enclosed in radiation shielding.

Circulating Separate Coolant

The simplest and most practical means of removing the heat from a pile appears to be by circulating a separate cooling medium through the reactor to carry away the heat generated therein. This heat-carrying fluid could then discharge its heat either directly to a heat engine or indirectly (by exchange) to a second medium.

Any fluid with the proper nuclear and physical properties can be employed for this purpose. Ordinary water is the cheapest and most easily handled and is probably the one with the best known properties. However, it must be carefully channeled through most piles so that it will not leak into the active section and add more water than is in the cooling channels. This would add more neutron absorbing material to the pile and affect the chain reaction, possibly even stopping it in some cases. This neutron absorbing property of the hydrogen component in the water also means that some sacrifice in nuclear fuel must be made when ordinary water is used as the coolant.

A phase change in any significant component of the active section of a pile changes the number of nuclei present and hence the reactivity and control of the pile. Therefore, water with its relatively low boiling point can only be used as a coolant in low pressure piles at low temperatures. To use it at higher temperatures in order to get the pile heat out in more useful form, much higher pressures must be employed so as to suppress all boiling or bubble formation while the water is in the pile. After the water once leaves the pile, it can then be allowed to expand or flash into its more useful form as steam. The upper limit, of course, is operation at the critical temperature and pressure of water, but this probably would be less desirable than lower pressures because of the inhomogeneity in density and corresponding difficulty in pile control.

Heavy water (D_2O) is another excellent liquid coolant, slightly heavier, but similar in almost every respect to ordinary water, but much more desirable because it does not absorb many neutrons and may even add a few neutrons from the (γ,n) reaction in the deuterium. However, it is very expensive and tends to get contaminated by hydrogen very readily by exchanging its deuterium component with the hydrogen component of any adjacent hydrogenous compounds. This means that unusual care must be taken in its handling and against leakage or contamination in the recirculating system. Hydrocarbons and deuterocarbons are other potential liquid coolants but the same objections that were raised to their use as moderators are applicable in considering them as coolants. These could not be used long without replacement or reprocessing.

For piles operating at higher temperatures for the production of useful power, molten metals such as sodium, potassium, lead or bismuth, or eutectics of sodium and potassium or of bismuth and lead might be used under the proper conditions. Of course, all of these, except the sodium-potassium eutectic, are solid at room temperature so that special means must be added to keep

the metals in the recirculating system liquid at all times, or else means provided for melting them when the system is started up. This complicates the mechanical design of the auxiliary system for using heat removed from the pile.

Likewise, the molten metals can hardly be used directly in any heat engine. Therefore, if the heat is to be converted into useful power, the molten metal must recirculate in a closed cycle through the pile and give up its useful heat in a heat exchanger to some second medium that can be utilized directly in a heat engine. Thus, almost every molten-metal-cooled pile must have a binary cooling system such as will be described in a later article in this series.

Mercury is probably the one exception to the limitation given above and could be used directly in a mercury turbine for transforming the heat picked up by the mercury to useful power. Unfortunately, mercury has such a high neutron absorbing capacity at low energies that it is not practical or, in many cases, even usable as a coolant in any piles except fast reactors, and not even in all of these.

Molten salts are another type of possible liquid coolant for operation at high temperatures. However, these not only have the same objection as most liquid metals in that they are usually solid at room temperature, but they are less desirable than the liquid metallic elements because they all have compound molecules that are subject to decomposition under irradiation.

Gaseous Coolants

Another type of coolant for any type pile operating at any temperature is a gas, such as air, carbon dioxide, hydrogen or helium. The gases are particularly useful in removing the heat from the very high temperature piles, especially in ranges near or above the boiling point of the molten metals. In fact, as far as the coolant gases themselves are concerned, there is practically no upper limit to the operating temperature at which they can be used, since the materials of construction of the pile and its auxiliary equipment define the upper operating temperature limit probably long before thermal decomposition of the coolant gas takes place.

Of course, air is the most desirable coolant from many standpoints. It is plentiful, free, well-known in its properties, and always accessible so that it does not have to be carried along with a mobile power plant as a stored coolant. Like ordinary water, it does not have to be saved and recirculated over and over again but can be thrown away after one pass through the pile, while the other gases must be recirculated through the reactor in a closed cycle. However, air contains oxygen which corrodes metallic nuclear fuels and moderators and decomposes many carbides, nitrides, *etc.*, at elevated temperatures. Therefore, air-cooled piles must be made either with the fuel and moderator in the form of the metallic oxides or else with the cooling ducts for the air closed off from the fuel and moderator by suitable jackets or sheaths which define the cooling channels.

Air has another disadvantage in some reactors in that some of the argon in the air is made radioactive by neutron bombardment in the pile. Since air is so applicable to open-cycle power plants, this somewhat long-lived radioactive argon in the discharged air may constitute a health hazard unless properly disposed of.

Still another objection to air occurs in large piles or in those under very high pressures. Air contains 80% nitrogen, a fairly good neutron absorber. If the air pressure in the pile undergoes any change, the number of absorbing nuclei of nitrogen also changes and affects the reactivity and control of the pile. In a large pile,

(*Continued on page 26*)

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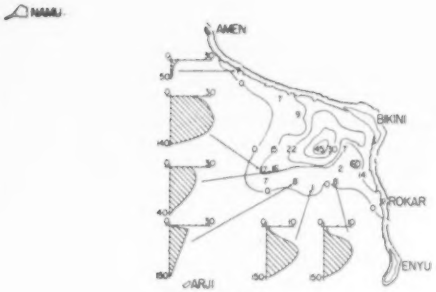

RADIOACTIVE WASTE DISPOSAL— How Will It Affect Man's Economy?

This is the question that underlies the more immediate one of where and how users of radioactive materials will dispose of their wastes. Among the answers provided here to the latter question may be found some clues to the former.

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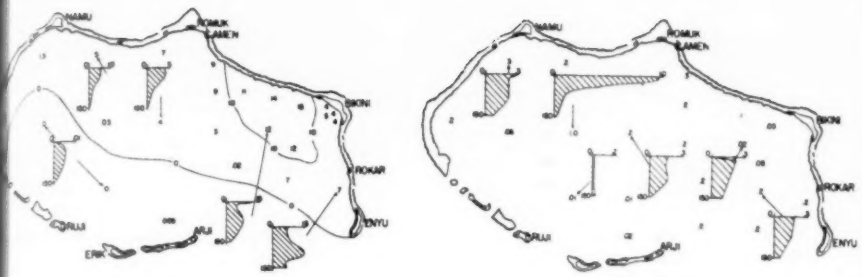
UNLIKE other members of the species, man has utilized his intellect not to seek success in survival by adaptation but rather to attempt changes that result in a more suitable environment. Some of man's environmental changes since the advent of the machine age have been geophysical changes.

An example may be that offered by the new atomic-energy industry. Large amounts of radioactive materials will be produced. After their period of usefulness, these materials fall into the category of radioactive wastes and present the problem of unwanted ionizing radiations. Methods of safe disposal must be worked out before the products of nuclear energy can be used to the full benefit of mankind. Many intangible factors arise whenever disposal of radioactive wastes is under consideration.

Legal Responsibility

Not the least of these factors is the legal responsibility which the disposer assumes when radioactive materials are allowed to be disseminated in areas used by the general public. This matter is not easy to evaluate for the following reasons.

Short-term effects of ionizing radiations upon some living things have been partially evaluated, but it is not possible at this time to foresee the sum total of such radiations over a long



Whether consignment of radioactive wastes to the ocean is a safe procedure depends, among other factors, on rapid dilution. Tests such as those of the diffusion of radioactive water mass following the Baker burst in Bikini lagoon may help to shed light on the problem. Values given on the four maps above denote relative concentration only and not radioactive decay or intensity. The isolines represent equal magnitudes of relative concentration. Vertical distribution is illustrated by shaded areas in various depths in feet.

period of time as they may concern man directly or be related to his economy. Scientific facts as opposed to legal evaluations of injury have not always been handmaidens in the courts.

It becomes necessary, therefore, to consider not only if the radiations from waste isotopes are going to exceed the permissible dose of 0.05 roentgens per day to living things in the area of their disposal, but also if it is possible to demonstrate waste activities in public facilities at all.

The high technical development of radiation detection instruments makes it easy to count very low levels of radioactivity. An amount of radiophosphorus that would give a below-permissible-level internal radiation rate of 0.049 rep* per day per gram of tissue can be detected to the extent of 10 counts per second with a Geiger-Müller counter. Activities of this order are quite impressive to the layman who might be called upon to decide a suit for injury.

The estimates which follow concerning the safe disposal of radioactive wastes are based upon the permissible level of 0.05 r per day and are now accepted as safe from a health-physics point of view. It must always be kept in mind, however, that these estimates do not necessarily represent levels that will keep the radioactive waste disposer free of legal entanglements.

Radioisotope Disposal in Institutions

The use of radioisotopes in scientific investigations and for human therapy presents the problem of waste disposal to every scientific institution and hospital that employs them. The annual reports of the Atomic Energy Commission indicate the number of users in this category is continually increasing.

The problem of waste disposal for the Medical Center of the University of California at San Francisco is offered as an example. In this case, it appears that in the future dangerous quantities of wastes might result primarily from radioisotopes used in therapy. The majority of such wastes will stem from the excreta of patients being treated with radioisotopes.

Although it was impossible to predict accurately how many patients may be

* Roentgen-equivalent-physical.

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treated with radioisotopes and with which particular isotope, an attempt has been made to measure the magnitude of the Medical Center's waste-disposal problem. See Table 1. It is based upon a total of 50 patients receiving radioisotope therapy and gives the total radioactive wastes that may accrue from them.

The radioactive waste output from such a group of patients may be as great as one curie per day. This level of disposal has been used as the basis for the following calculations if this material is to be admitted to the public sewer system. The calculations are based upon the assumption that there will be no accumulation of radioisotopes in the various traps and sumps peculiar to modern plumbing. The reason for this does not lie in the thought that it might not occur with respect to such elements as the lanthanide rare earths, but at this point of development of the problem, it is not possible to assay the possibilities quantitatively with any certainty.

The first step in the disposal of radioactive wastes from a therapeutic ward in a hospital would be their dilution by the sewage flowing from the ward housing such patients. The average ward output of sewage is about 640 liters per day per patient. If one curie of the activities, as mentioned above, were present in such a volume, proximity to liter quantities enclosed in drains, *etc.*, would approach radiation levels of 50 milliroentgens per day. Skin doses of radiation from an unshielded solution would be about 40 times greater than this figure.

Five cubic centimeters of such a solution would show an activity in excess of 1,000 counts per second on a beta-sensitive counter. Large amounts of such a solution would be unsafe to handle or work nearby. If one curie were to be diluted with the entire sewage output of the University of California Medical Center, which is estimated to be 5×10^8 liters per day, it would produce enough gamma rays to give radiation levels of 3 mr per day in liter quantities. A 5-cc sample would have a readily demonstrable activity of over 50 counts per second.

Contamination of Public Sewer System

The Medical Center sewage is admitted into the system which serves one area of San Francisco. The combined raw sewage is processed at a filter plant, the total daily volume being estimated at 2.7×10^7 liters. A curie of waste radioactivity diluted to this volume would still show a demonstrable activity of about 100 counts per minute in a 5-cc sample. Exposure of less than 0.1 mr per day would be produced from the gamma rays of such a solution.

It is common practice, however, with this and other sewage plants to make economic use of the filter cake which is separated from raw sewage. Biological concentration of radioactive waste elements can easily occur since forms living in fresh water contain much more phosphorus and iodine than their medium. Such accumulation may be applied to rare earths as well. It is entirely possible that filter cake concentrated from a large volume of radioactive fluid such as raw sewage might contain a majority of any radioelements present.

This material is frequently returned to the economy of man, and the inclusion of radioactive wastes within it is of interest for this reason. One curie of radioactive wastes in the filter cake produced from the above mentioned volume of sewage would amount to a concentration of about 0.1 microcurie per gram. Filter cake is sometimes used for fertilizing purposes in public parks and the like. Unwitting contact with such material could deliver skin doses as high as 2 rep per day. Activities of such concentrations are easily

TABLE 1

Estimate for One Hospital of Radioactive Excretions from Patients Receiving Radioisotope Therapy

Number of Patients	*Isotope to be Used*	*Probable Dose (millicuries)*	*Excretion (millicuries)*	
			Average Daily	*Total Daily*
20	I^{131}	100	50	1,000
20	P^{32}	20	1	20
10	Fission Products Rare Earths	100	1	10

detectable and are capable of fogging ordinary photographic film in a few hours. The processing of filter cake contaminated to this extent would present health physics problems to any organization concerned with it.

A consideration of the possibilities mentioned here points to the fact that the dissemination of radioactive wastes into areas available to the public must be looked upon with concern. The disposal of more than 50 millicuries of radioactive wastes per day by the University of California Medical Center was not recommended. This value is somewhat more conservative than the 200 millicurie limit suggested by the Atomic Energy Commission in its Interim Recommendations for Disposal of Radioactive Wastes by Non-AEC Users (*1*). The wisdom of setting any limit whatsoever for any one user must be questioned since most large urban areas generally have several institutions which may effect waste disposal via the public sewer system.

Existing Methods of Waste Disposal

Atomic Energy Commission Circular B-6 illustrates several possibilities of waste disposal. They are: 1) Dilution of radioactive materials with stable isotopes of the same element in the same chemical form to prevent reaccumulation following dispersion. 2) Dispersion in media such as air or water. 3) Confinement and dilution such as the inclusion of radioactive wastes within concrete. 4) Concentration and confinement in storage in tanks after the volume of the waste has been reduced.

As far as health protection is concerned, any of these methods appears to be safe if the radiation level of 0.3 r per week continues to be considered safe as man becomes more experienced with ionizing radiations. It should be realized, however, that the suggested methods do not relieve the waste disposer of possible legal entanglements. The storage of radioactive wastes is expensive in that it necessitates a separate waste-collection system. Construction costs for the storage of large volumes of waste are estimated to approach 70¢ per gallon.

A ten-patient ward concerned with radioisotope therapy would have an estimated waste output of 1,800 gallons per day. The rigid exclusion of nonradioactive liquids might reduce this by a factor of 10. It would be necessary to hold such wastes for a period of five half-lives before decay could be an appreciable factor. Given an average half-life of ten days, it would appear that two tanks with a capacity of approximately 10,000 gallons would be needed. This would represent an investment of around $20,000, and considerable attention would have to be

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given to a separate waste-collection system that could not be contaminated readily with the radioactive materials being used.

Because of the variety of radioisotopes which may be used, it does not appear that plumbing components are available that either would not become contaminated or would be easily decontaminated. Such a waste-disposal facility represents an initial investment which must be made whether the facility is used or not.

Because the successful use of large amounts of radioisotopes in human therapy is not at all well established, one might question the advisability of making major investments for waste-disposal using the concentration and/or confinement method. Wherever possible, the unit method of disposal is more attractive in the economic sense because of the fact that this method becomes an expense only when it is used and the expense is related to the frequency of use. Such units may be composed of shielded containers which can be stored in otherwise non-useful areas or consigned to the sea.

Waste Disposal in the Oceans

Waste disposal at sea, of course, immediately brings up the possibility of contamination of an area that is vital to the economy of man. Several problems come to mind with the disposal of radioactive materials into the sea, because man's economy is dependent upon it to a great extent. They revolve around raising the amount of ionizing radiations in sea water and the effect of such radiations upon the life in the sea. It is a matter of interest then to consider:

1) the amount of radioactive materials which can be disseminated
2) their half-lives and thus their effectiveness over appreciable periods of time
3) the probable rates of diffusion and mixing of such waste products in sea water
4) the probability of reconcentration of radioactive wastes by the variety of biological forms within the sea.

Some insight into the first item can be gained by considering radiation levels to which sea life is exposed from the natural radioelements already present in the sea. These are primarily K^{40} and uranium and its decay products, the largest contributor being from K^{40}. This isotope of potassium has a half-life estimated to be 1.4 to 1.9×10^9 years (*2*).

At the present time, the abundance of K^{40} is 0.11% of all of the potassium in nature. Because sea water contains 0.4 grams of potassium per kilogram, the K^{40} concentration is 42 micrograms per kilogram or about 8×10^{17} atoms. Each kilogram of sea water absorbs the energy from 12 disintegrations of K^{40} per second resulting from its decay.

Some additional ionization is caused from the decay of uranium present in sea water (0.0015 μg per kg) but this is not large compared to K^{40} (*3*). For example, the UX_2 produced in uranium decay contributes less than 0.02 disintegrations per sec per kg of sea water. It is necessary to conclude that there are large amounts of radioactivity already present in the sea since one cubic kilometer of sea water contains 330 curies of K^{40}.

The total volume of the oceans has been calculated to be 1.37×10^9 cubic kilometers (*4*). For this reason, the store of K^{40} in the oceans is relatively enormous and is calculated to be about 5×10^{11} curies. Over 10^{10} curies of long-lived radioactive isotopes would have to be disposed of in the sea to raise the radiation level 10%. Inclusion of this amount of activity in the sea would subject the life in the oceans to radiation levels which existed 200

million years ago providing the K^{40} concentration was the same. However, the lower salt concentration of the body fluids of terrestrial animals presumed to have originated from the sea make this point disputable.

Diffusion of Radioactivity in the Oceans

Consignment of radioactive wastes to the oceans may be safe providing there is relatively rapid dilution in turbulent waters and re-accumulation is avoided.

Studies conducted by the Radiological Safety Section at Bikini showed that fission products, the majority of which had relatively short half-lives, were capable of being diluted and mixed with the sea water present in Bikini lagoon. Water samples were taken from the original body of radioactive water at intervals after the atomic burst. Typical horizontal and vertical distribution values are shown in the four maps on pages 18–19 for various time periods following the bomb burst. The values given there are not related to radioactivity or radioactive decay. They represent only the degree of dilution of the original radioactive water mass with other sea water present in the lagoon. Mixing of the original radioactive water mass with the rest of the lagoon water was complete in eight days, the rate of mixing being related to the weather conditions in effect at that time.

To the author's knowledge, this is the first time radioactive materials were used as tracers to follow the movement of water masses in a large-scale oceanographic study. The data obtained upon diffusion in Bikini lagoon using radioactive tracers have been compared with those using more classical methods.

Ford has compared the diffusion of fission products admitted to Bikini atoll by the Baker blast with diffusion studies as pictured by salinity measurements (*5*). He reported that the diffusion of the radioactive water masses in Bikini lagoon agreed with the observations based upon salinity measurements. Munk *et al.* made similar comparisons in which horizontal diffusion of fission products was compared to the lateral spread of dye markers (*6*).

In addition to this, the state of turbulence in the lagoon was estimated by simultaneous measurements of surface current and wind speed, measurements of diurnal temperature fluctuations at various depths, and measurement of the rate of mixing of oxygen-rich reef water with the body of the lagoon water.

Biological Accumulation

The question of biological accumulation remains to be considered. The data obtained upon the diffusion of fission products at Bikini represented primarily the fate of the shorter-lived isotopes, since at the time of measurement they represented the major part of the radioactivity present. Owing to radioactive decay, any long-term biological accumulation of radioactivity in the sea would involve only the longer-lived isotopes.

With the exception of C^{14} and Co^{60}, radioelements with long half-lives are to be found primarily among the fission products. However, these represent but a small part of the total activity produced at the time of fission. This is easily illustrated by the decay curve of the fission products which has been reported by Way and Wigner (*7*). It can be seen from their data that the disintegration rate at 1 second after fission is reduced by a factor of ten thousand at 1 day, 200 thousand at 10 days, and 100 million at 1 thousand days. Thus at the end of 3 years after fission, less than 1×10^{-6} per cent of the initial activity remains, and the radioisotopes predominantly present have half-lives of a year or more.

Since isotopes of all of them, with the possible exception of promethium, al-

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TABLE 2

Isotopic Concentration in Sea Water of Some Long-lived Radioisotopes Formed by Fission

Isotope	*Half-life*	*Fission Yield*	*Isotopic Concentration in Sea Water (mg/kg sea water)*
Rb^{87}	6.3×10^{10} yr*	.....	0.2
Sr^{90}	25 yr	.....	13.0
Ru^{106}	.....	0.5%	
$Sn^{121,123}$	130 days	1.2×10^{-3}	Present; see (*13*)
I^{129}	long	.....	0.05
Cs^{137}	37 yr	.....	0.002
Ce^{144}	275 days	5.3%	0.004
Pm^{147}	3.7 yr		
Eu^{155}	2 to 3 yr		

* A naturally radioactive isotope with abundance of 27.2% of all rubidium (*9*).

ready occur in nature and probably in sea water, the distribution of such radioisotopes will be similar to the distribution of the naturally occurring isotopes when their equilibrium states are reached. *Phases of biological accumulation may occur in local areas, however, before such equilibrium is reached.*

The majority of the longer-lived radioisotopes formed from fission have been summarized in Table 2 along with values obtained for the concentration of similar naturally occurring elements in sea water (*8*). Since radioactive materials will ultimately be in equilibrium with the stable isotopes already present in the sea, the matter of waste disposal at sea by dilution becomes primarily a concern over the possibility of biological accumulation before the dispersal is complete.

The majority of the elements listed in Table 2 are selectively accumulated by marine organisms, although the data obtainable are not complete for some of the lanthanide rare-earth series such as promethium or europium, or for ruthenium. For example, rubidium has been widely demonstrated in plants and animals (*10*). Strontium has been shown to be a constituent in marine invertibrates as well as in the calcarious skeletons of sea organisms (*11*). Tin has been found in the starfish, sea urchin, and gastropod mollusk (*12*). The accumulation of iodine by terrestrial and aquatic vertebrates is well known. It is selectively absorbed by the sponges and sea weed (*14*), as well as by other marine organisms.

The examples of biological accumulation cited direct one's attention to the possibility of the accumulation of waste radioactive elements. Areas near points of waste dissemination may well accumulate enough radioactivity to interfere with the economic usefulness of such regions if the disposal method used is one of dilution.

These factors point to the need for the development of waste disposal methods which will prohibit the diffusion of unwanted radioactive materials in the sea wherever the possibility of accumulation is present. If a container can be developed that will prevent the diffusion of radioactive materials, then such wastes might be consigned to sediment-forming ocean trenches which are accessible to every continental land mass.

In summary, it is suggested that waste disposal not be conducted in areas available to the public. Disposal in the oceans is desirable providing

temporary biological accumulation does not become an embarrassment. From the facts now available, permanent storage in land or in sea for the effective half-life of the material is suggested as the only safe method of disposal.

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Engineering Aspects of Nuclear Reactors (*Continued from page 17*)

changes in barometric pressure alone might be enough to affect the operation and control of the pile.

Carbon dioxide is a compound molecule. While it is normally inert and does not corrode the pile components, it breaks down or decomposes partially under neutron bombardment. Hence, the oxygen released may cause some oxidation, although this effect is probably small in most piles. However, since this gas is probably one that will not be wasted but will be recirculated through the pile, repeated irradiation introduces as great a corrosion problem as with air unless proper precautions are taken.

Hydrogen is a neutron absorber, slowly changing to deuterium with a release of gamma radiation. As long as oxygen is kept out of the system, however, hydrogen is inert to most materials, even at high temperatures. Of course, if oxygen should get into the cooling system, corrosion is not the only problem, since the hazard of explosion is quite obvious.

Helium alone is completely inert chemically and is stable from a nuclear standpoint. The only objection to it is that which applies equally to all gases that must be recirculated through the pile instead of being thrown away after one pass. The heat exchanger for transferring the heat from the closed cycle through the pile to the other cycle of the binary cooling system must be very large or very heavy in order to get any appreciable quantity of power out of the system.

All the gases have one advantage over other fluid coolants. In trying to get large quantities of heat out of very small reactors, it becomes physically impossible to get much heat transfer surface in a small volume of pile by any exchanger principle except that of a porous block. It is easier to pass large quantities of gases through porous block piles than any other fluid coolant. **END**

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STATISTICS OF COUNTING

This article serves three purposes: 1) It gives a direct and systematic treatment of the statistics of counting, 2) it presents the use of the Laplace transform as a tool for computing the results of a statistical analysis, and 3) it presents the computation and a nomograph for scaler losses.

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A NUMBER OF ARTICLES on the statistics of counting nuclear particles have been written, and the solution of most problems that are encountered in applications of the theory to practical cases are well understood (*1*). The main purpose of this article is to present a discussion of the use of the Laplace transformation for finding the moments of probability distributions, with applications to counting losses in scaling circuits having a finite resolving time, at both the input and a later position in the scaling circuit. The material in the first part of the paper is included primarily for background purposes.

Random Distribution of Events in Time

We postulate that the occurrence (or non-occurrence) of an event in any interval of time is purely a matter of chance, restricted only by the existence of a definite average rate of occurrence of events. To develop a statistical theory of such a *random* sequence of events, let us pick any one event as an origin in time, and let q be the probability that one unit of time elapses before the next event occurs. Then the probability that two units of time elapse is q^2, and that t units of time elapse is q^t. Since $q < 1$, let us set $q = e^{-\alpha}$, where α is a positive constant, so that $e^{-\alpha t}$ is the probability that t units of time elapse between any two successive events.

The probability that the event takes place in the time interval from 0 to t is $P_1 = 1 - e^{-\alpha t}$, from which we find that

$$dP_1 = \alpha e^{-\alpha t} dt \qquad (1)$$

is the probability that the event occurs in the interval dt at time t. If $\bar{t}$ is the average time interval between successive events, and n is the average number of events per unit time, then

$$\bar{t} = \frac{1}{n} = \int_0^\infty t\alpha e^{-\alpha t} dt = \frac{1}{\alpha} \qquad (2)$$

so that α is equal to n, the average rate at which events occur. We thus see that the probability of an event occurring in the interval dt at a time t following the last previous event is $dP_1 = ne^{-nt}\,dt$.

The *probability density* is given by

$$p_1(t) \equiv \frac{dP_1}{dt} = ne^{-nt} \qquad (3)$$

which, for this case, decays exponentially with time. The fact that

$$\int_0^\infty p_1(t)dt = 1$$

expresses the certainty that each succeeding event occurs, provided one waits long enough. However, an event is more likely to occur in an interval dt immediately following a previous event, than in a later interval. The notion that pairs of events are most likely to be separated by the average interval

between events is, of course, quite incorrect.

In the analysis leading to Eq. 3, we chose an event as a time origin, since, in the application of this equation to counting losses in recording equipment, this interpretation will always be used. A little consideration shows, however, that if we choose an arbitrary instant in time as time origin, we are again led to Eq. 1, although it is not quite as obvious that α must equal n for this case. Instead of attempting to show that this must be true, we shall tentatively assume that $\alpha = n$ when the time origin is arbitrarily chosen, and justify the assumption after obtaining the Poisson distribution.

From the probability density $p_1(t)$ (considering the time origin to be either at an event or at an arbitrary instant in time), all the various statistical relations involved in counting events occurring at a constant average rate and having a random distribution in time can be deduced. In the present account, we shall first find the density function for every mth event. This density is important in the theory of scaling circuits, and it affords an easy means of obtaining the well-known Poisson distribution. We shall then introduce the use of the Laplace transformation as a means for obtaining various moments of particular distributions. Finally, we shall consider the effect on observed counting rates of the finite resolving time of counting circuits.

Probability Density

We seek the probability dP_m that the mth event following the 0th event at $t = 0$ occurs in the interval dt at time t. Let us consider first the case for $m = 2$, for which a possible sequence of events is shown in Fig. 1. The probability that the first event occurs in an interval $d\lambda$ at a time $\lambda \leq t$ is $p_1(\lambda)d\lambda$. The probability that the second event occurs in dt at a time $t - \lambda$ after the first event

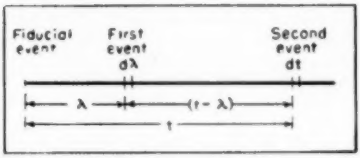

FIG. 1. Time relations in a sequence of three random events

is $p_1(t - \lambda)dt$. The probability for this particular sequence of events to occur is the product of the two probabilities, $p_1(\lambda)p_1(t - \lambda)d\lambda dt$. However, the value of λ is immaterial, provided only $0 \leq \lambda \leq t$. Hence dP_2 is given by the sum (here an integral) of the various mutually exclusive probabilities, that is,

$$dP_2 = dt \int_0^t p_1(\lambda)p_1(t - \lambda)d\lambda \quad (4)$$

The probability density is therefore

$$p_2(t) = \frac{dP_2}{dt} = \int_0^t p_1(\lambda)p_1(t - \lambda)d\lambda$$

$$= n^2 e^{-nt} \int_0^t d\lambda = n^2 t e^{-nt} \quad (5)$$

The reasoning used can be immediately extended by mathematical induction to give

$$p_m(t) = n^m \frac{t^{m-1}}{(m-1)!} e^{-nt} \quad (6)$$

for the density governing the occurrence of every mth event. We note in passing that Eq. 6 also is the probability density of the mth event following an arbitrarily chosen time origin, provided α in Eq. 1 is identified with n.

Poisson Distribution

The Poisson distribution, giving the probability of finding exactly m events in a time T when the average rate of occurrence is n, can be deduced by noting that $\int_0^T p_m(t)dt$, which is the probability that the mth event occurs in the interval 0 to T, is also *the probability that at least* m *events occur in this interval.* Here, we must use the second interpretation of $p_m(t)$, in which the time origin is an arbitrary instant in time. Otherwise the interval T would

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have to start with an event. The probability that exactly m events occur in the interval T is therefore

$$P_m(T) = \int_0^T p_m(t)dt - \int_0^T p_{m+1}(t)dt$$

On using Eq. 6 and integrating the second integral once by parts, we are led to the Poisson distribution

$$P_m(T) = \frac{(nT)^m}{m!} e^{-nT} \qquad (7)$$

The expected number of events in the time interval T is

$$\overline{m} = \sum_{m=0}^{\infty} mP_m(T) = nT \qquad (8)$$

and the standard deviation squared

$$\sigma^2 = \sum_{m=0}^{\infty} (m - \overline{m})^2 P_m(T)$$

$$= nT = \overline{m} \qquad (9)$$

The method by which the infinite series in Eqs. 8 and 9 are summed will not be given here, but can be found in (*1*). The evaluation of $\overline{m}$ and σ^2 can also be made by an extension to discrete distributions of the method using the Laplace transformation, given in the next section, for continuous distributions.

At this point, we can justify the assumption that $\alpha = n$ when the time origin is arbitrarily chosen. Without this assumption Eq. 8 takes the form $\overline{m} = \alpha T$, that is, $\alpha = \overline{m}/T$, which is the experimental definition of the average counting rate n. In the problems involving counting losses, which will be considered later, the time origin of probability densities will be taken at an event.

The results expressed by Eqs. 8 and 9 are important in assigning the probable error to a counting rate determined by an observation of m counts in a time T. Thus, a counting rate determined with m counts has a fractional probable error $0.6745/\sqrt{m}$, to a good approximation. The factor 0.6745 is the ratio of the probable error to the standard deviation for observations obeying the normal error law, which can be shown to be a good approximation to the Poisson distribution for large values of m. [See (*1*) for additional discussion of this distribution.]

Moments of Probability Distributions

We have already made use of the fact (in Eq. 2) that

$$\overline{t} = n \int_0^{\infty} te^{-nt}dt = \frac{1}{n}$$

gives the average spacing of successive events. The integral $\int_0^{\infty} tp(t)\,dt$, where $p(t)$ is a density function, is spoken of as the *first moment* of the distribution. In general, the rth *moment* is defined by

$$\overline{t^r} = \int_0^{\infty} t^r p(t)dt \qquad (10)$$

In most applications, the average spacing of events $\overline{t}$, which is given by the first moment, and the standard deviation σ, which depends on both the first and second moments, are of greatest interest. The standard deviation, defined by

$$\sigma^2 = \int_0^{\infty} (t - \overline{t})^2 p\,(t)dt = \overline{t^2} - \overline{t}^2 \qquad (11)$$

is a measure of the spread of the distribution about the mean separation in time of the two events being considered, *i.e.*, the fiducial event at time 0, and the event having the probability density $p(t)$. Although it is possible to compute the various moments of a distribution directly, it is often easier, in practice, to determine them by use of the Laplace transformation of the function $p(t)$. The method is usually known as "the method of the moment generating function," but is here somewhat modified and couched in terms of the Laplace transformation, familiarity with which is assumed on the part of the reader. Knowledge of the useful properties of this transformation for treating transients in linear systems has become widespread in recent years (*2, 4*).

The Laplace transform (£-transform) of $p(t)$ is defined by

$$P(s) = \mathfrak{L}[p(t)] = \int_0^\infty p(t)e^{-st}dt \quad (12)$$

provided $p(t)$ satisfies certain mathematical requirements which are met by the functions arising in the statistics of counting, as treated here. If e^{-st} is expanded in ascending powers of st,

$$P(s) = 1 - \frac{s}{1!}\int_0^\infty tp(t)dt + \frac{s^2}{2!}\int_0^\infty t^2p(t)dt - \cdots \quad (13)$$

in which the first term is unity, since $\int_0^\infty p(t)dt = 1$. We see that the rth moment of $p(t)$ is given by the coefficient of $(-s)^r/r!$. Thus to determine $\bar{t}$ and σ, one finds the £-transform of $p(t)$ in a table of transforms [see Appendix B, in reference (2)], performs the expansion

$$P(s) = 1 + a_1s + a_2s^2 + \cdots \quad (14)$$

and uses the relations

$$\bar{t} = -a_1 \quad (15)$$

$$\sigma^2 = 2a_2 - a_1^2 \quad (16)$$

found by comparing Eqs. 13 and 14. The task of computing the counting rate $(1/\bar{t})$ and the standard deviation from a density function is thereby reduced to a matter of algebra, provided the £-transform, Eq. 12, can be found in a table without recourse to direct integration. In particular cases, many of the special theorems useful in applying £-transforms to transient problems will be of help here.

To illustrate the method, let us find $\bar{t}_m$ and σ_m for the distribution of every mth event of a random sequence of events. The density function for this case is given by Eq. 6, and it has the £-transform

$$P_m(s) = \left(\frac{n}{n+s}\right)^m \quad (17)$$

which can be obtained directly from a table of transforms [transform pair 2.121 (2)]. It is instructive, however, to obtain this transform using the theorem that [transform pair 9 (2)]

$$p_{m_1+m_2}(t) = \int_0^t p_{m_1}(\lambda)p_{m_2}(t-\lambda)d\lambda \quad (18)$$

has the £-transform

$$P_{m_1+m_2}(s) = P_{m_1}(s) \times P_{m_2}(s) \quad (19)$$

where $\mathfrak{L}[p_{m_1}(t)] = P_{m_1}(s)$, *etc.* Equation 18, of course, is simply a generalization of Eq. 5, and expresses the probability density for the $(m_1 + m_2)$th event in terms of the probability densities for the m_1th and the m_2th event. Now $p_1(t)$, given by Eq. 3, has the £-transform [transform pair 1.102 (2)]

$$P_1(s) = \frac{n}{s+n}$$

so that

$$P_2(s) = P_1(s) \times P_1(s) = \left(\frac{n}{s+n}\right)^2$$

and, in general, Eq. 17 holds.

The expansion of $P_m(s)$ in a power series in s

$$P_m(s) = 1 - \frac{m}{n}s + \frac{m(m+1)}{2n^2}s^2 - \cdots$$

gives

$$\left.\begin{aligned} \bar{t}_m &= \frac{m}{n} \\ \sigma_m^2 &= \frac{m(m+1)}{n^2} - \frac{m^2}{n^2} = \frac{m}{n^2} \end{aligned}\right\} \quad (20)$$

on using Eqs. 15 and 16. We thus have the familiar result that $\sigma_m/\bar{t}_m = 1/\sqrt{m}$, *i.e.*, the spread in the distribution of every mth event is reduced by the factor $1/\sqrt{m}$ compared with the spread in the distribution of successive events, for which $\sigma_1/\bar{t}_1 = 1$. This result, when applied to scaling circuits, is "the regularizing action of the scaling circuit."

Counting Losses

Two simple types of situations that result in a loss of counts can be distinguished. In one type, each pulse accepted by the counting circuit excites a certain deadtime in the circuit, during which any pulse that occurs is rejected. The rejected pulse does not further extend the deadtime of the circuit. It

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is usually assumed that scaling circuits behave in this manner. In the second situation, every pulse that occurs excites the deadtime, whether or not the pulse is counted. The counting setup is then said to have an extended deadtime, or resolving time.

It is likely that pure cases of the two types of resolving times do not occur in practical circuits, but, for approximate calculations, one or the other can be assumed. Counting losses resulting from both types become almost identical when the counting loss is small. To distinguish experimentally between the two types, the resolving time of a circuit, such as a scaler, should be measured with groups of at least three test pulses, whose separation in time can be independently varied. With pairs of pulses of controllable separation, one cannot distinguish between an extended and a nonextended resolving time.

To compute the rate at which counts are accepted by a circuit having a nonextended resolving time τ_1, one modifies the density function $p(t)$ of the incoming pulses (events) by making it zero from $t = 0$ to a time $t = \tau_1$, and then restores it to its original value. This can be done analytically by multiplying $p(t)$ by $u(t - \tau_1)$, a delayed unit step function rising from 0 to 1 at $t = \tau_1$. Since $\int_0^\infty u(t - \tau_1)p(t)dt = A < 1$, the modified density function can be normalized by including the factor $1/A$. The average separation of counts, which is the reciprocal of the observed counting rate, is

$$\bar{t} = \int_0^\infty tp^*(t)dt \qquad (21)$$

where $p^*(t)$ is the normalized, modified density function,

$$p^*(t) = u(t - \tau_1)p(t) / \int_0^\infty u(t - \tau_1)\ p(t)dt \qquad (22)$$

The counting rate for an extended resolving time can also be computed from Eq. 21, provided one can manage to find the modified density function that holds for this case. Even in simple problems, the density function takes on a complex analytical form, making it desirable to use another method for computing the observed counting rate. Thus, with an extended resolving time τ_1, each event that occurs, whether it is counted or not, paralyzes the circuit for a time τ_1, in which interval no events are counted. Therefore only the fraction $\int_0^\infty u(t - \tau_1)p(t)dt$ of all the events are counted, making the observed counting rate

$$n_{obs.} = n \int_0^\infty u(t - \tau_1)p(t)dt = nA \qquad (23)$$

where n is the rate at which events occur. The integrals in Eqs. 21 and 23 can be evaluated most readily using the method of the $\mathcal{L}$-transform outlined in the last section. The value of A is nothing but the zero moment of the unnormalized density function, and is given by the first term in the expansion of $P^*(s)$ in powers of s. In Eq. 13, the first term is unity, since the density function considered there is normalized.

Counting losses are expressed in terms of the fractional counting loss

$$f = \frac{n - n_{obs.}}{n} \qquad (24)$$

As a first example, suppose the input of a recording circuit has a nonextended resolving time τ_1. The unnormalized density function for the pulses accepted by the circuit is

$$p_1^*(t) = u(t - \tau_1)p_1(t) = u(t - \tau_1)ne^{-nt} \qquad (25)$$

where $p_1(t)$ is given by Eq. 3, and where $u(t - \tau_1)$ is a delayed unit step occurring at $t = \tau_1$. The effect of the step function on the density function $p_1(t)$ is illustrated in Fig. 2, which also shows the normalized density function. We note that the normalized density has the form of $p_1(t)$, but has its time origin

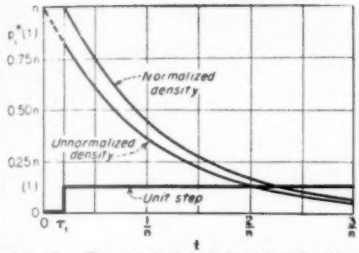

FIG. 2. Effect of the delayed unit step function $u(t - \tau_1)$ on the density function ne^{-nt}

displaced τ_1 to the right. This is in accord with the notion mentioned earlier that the time origin of $p_1(t)$ can be taken at an arbitrary instant of time, as well as at an event. The £-transform of $p_1^*(t)$ is

$$P_1^*(s) = e^{-\tau_1(s+n)} \frac{n}{s+n} \qquad (26)$$

[use transform pairs 10 and 1.102 (2)]. Expanding $P_1^*(s)$ in a power series in s,

$$P_1^*(s) = e^{-n\tau_1}\left[1 - \left(\tau_1 + \frac{1}{n}\right)s + \left(\frac{\tau_1^2}{2} + \frac{1}{n^2} + \frac{\tau_1}{n}\right)s^2 - \cdots\right] \qquad (27)$$

where $e^{-n\tau_1}$ has been factored out of the series to make the series in the brackets start with unity. The series in the brackets is therefore *the expansion of the £-transform of the normalized density function*. From Eq. 27, we find that

$$\left.\begin{aligned} A_1 &= \int_0^\infty u(t-\tau_1)p_1(t)dt \\ &= e^{-n\tau_1} \\ \bar{t}_1 &= \tau_1 + 1/n \\ \sigma_1^2 &= 1/n^2 \end{aligned}\right\} \qquad (28)$$

This example shows how the computation involving Eqs. 25, 26 and 27 gives a value of A, the area under the unnormalized density curve, as well as values of $\bar{t}$ and σ. The normalized density corresponding to Eq. 25 is

$$p_1^*(t) = u(t - \tau_1)ne^{-n(t-\tau_1)} \qquad (29)$$

which has the £-transform

$$P_1^*(s) = e^{-\tau_1 s}\frac{n}{s+n} \qquad (30)$$

The observed counting rate follows from $n_{obs.} = 1/\bar{t}_1$, and Eq. 28, *i.e.*,

$$n_{obs.} = \frac{n}{1 + n\tau_1} \qquad (31)$$

giving the fractional counting loss

$$f = \frac{n\tau_1}{1 + n\tau_1} \qquad (32)$$

The standard deviation is unchanged by the counting loss.

As a second example, suppose that the input circuit has an extended resolving time τ_1. We then have from Eq. 28 that $A_1 = e^{-n\tau_1}$, and since

$$\bar{t} = \int_0^\infty tp_1(t)dt = \frac{1}{n}$$

in the absence of any loss, Eq. 23 gives the well-known result

$$n_{obs.} = ne^{-n\tau_1} \qquad (33)$$

with the fractional counting loss

$$f = 1 - e^{-n\tau_1} \qquad (34)$$

As a third example, which is more complex mathematically, we shall consider the case of a scaling circuit in which a nonextended resolving time τ_1 exists at the input, and a second nonextended resolving time τ_2 exists after a scale-of-m. This case differs from that treated by Alaoglu and Smith (3) in which the resolving time τ_2 was considered as extended (that of a message register). The case considered here is of help in choosing the number of stages for a fast pre-scaler, which is designed to have as short a resolving time as possible, and is meant to be used preceding a conventional (commercial) scaler having a moderate resolving time, *e.g.*, 5 μsec.

To solve this problem we first obtain the modified density function $p_m^*(t)$ taking into account the resolving time τ_1 at the input of the scaler. This may be done most readily using the theorem expressed by Eqs. 18 and 19, which, on repeated application, gives for the £-transform of $p_m(t)$

$$P_m^*(s) = [P_1^*(s)]^m = e^{-m\tau_1 s}\left(\frac{n}{s+n}\right)^m \qquad (35)$$

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where $P_1^*(s)$ is given by Eq. 30. The normalized, modified density function is the inverse transform of Eq. 35

$$p_m^*(t) = u(t - m\tau_1)n^m \times \frac{(t - m\tau_1)^{m-1}}{(m-1)!} e^{-n(t-m\tau_1)} \quad (36)$$

[use transform pairs 11, 2.102, and 10 (2)]. If now we introduce the second resolving time τ_2 following a scale-of-m, the new density function, in an unnormalized form, becomes

$$p_m^{**}(t) = u(t - \tau_2)u(t - m\tau_1)n^m \times \frac{(t - m\tau_1)^{m-1}}{(m-1)!} e^{-n(t-m\tau_1)} \quad (37)$$

This equation is obtained from Eq. 36 by removing the first part of the distribution by the inclusion of a unit step function factor delayed a time τ_2, as was done in the case of Eq. 25 for the simple problem treated there. The factor $1/A_m$ required to normalize $p_m^{**}(t)$ can be found from its £-transform which we shall now find.

The £-transform takes two different forms, one for $\tau_2 \geq m\tau_1$ and another for $\tau_2 \leq m\tau_1$, the two becoming identical if $\tau_2 = m\tau_1$. The reason for this behavior is not difficult to understand, for if $\tau_2 \leq m\tau_1$, it is not possible for a counting loss to occur at the input of the $(m+1)$th stage. The fractional counting loss given by Eq. 32 then holds, and need not be recalculated here.

Let us therefore consider the case for $\tau_2 \geq m\tau_1$. This condition allows us to remove the factor $u(t - m\tau_1)$ from $p_m^{**}(t)$, since the other unit step function keeps the density function zero for a time $\tau_2 \geq m\tau_1$. With this observation we find that the transform is [use transform pairs 10, 2.102 and 11(2)]

$$P_m^{**}(s) = n^m e^{-\tau_2 s - n(\tau_2 - m\tau_1)} \times \sum_{r=0}^{m-1} \frac{(\tau_2 - m\tau_1)^r}{r!} \left(\frac{1}{s+n}\right)^{m-r} \quad (38)$$

If we put $\tau_m \equiv \tau_2 - m\tau_1$, the first part of the expansion of $P_m^{**}(s)$ in powers of s takes the form of Eq. 39 (see below) which gives for the area under the distribution curve

$$A_m = e^{-n\tau_m} \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!} \quad (40)$$

and for the average spacing of counts

$$\overline{t_m} = \tau_2 + \frac{\sum_{r=0}^{m-1} (m-r)\frac{(n\tau_m)^r}{r!}}{n \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!}} \quad (41)$$

We shall not take space to compute σ^2 here.

The fractional counting loss is found to be

$$f_m = \frac{\frac{(n\tau_m)^m}{m!} + n\tau_1 \exp_{m-1}(n\tau_m)}{\exp_m(n\tau_m) + n\tau_1 \exp_{m-1}(n\tau_m)} \quad (42)$$

in which the notation

$$\exp_m(x) = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \cdots + \frac{x^m}{m!}$$

has been used for the incomplete exponential series having $m+1$ terms.

For the purpose of computing values of f_m from Eq. 42, the equation can be transposed to

$$\frac{f_m}{1 - f_m} = n\tau_1 + \frac{\frac{(n\tau_m)^m}{m!}}{\exp_{m-1}(n\tau_m)} \quad (43)$$

$$P_m^{**}(s) = e^{-n\tau_m} \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!} \left[1 - s\left(\tau_2 + \frac{\sum_{r=0}^{m-1} (m-r)\frac{(n\tau_m)^r}{r!}}{n \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!}} \right) + \cdots \right] \quad (39)$$

which is also a convenient form on which to base a nomograph relating f_m, $n\tau_1$, and $n\tau_m$ for a chosen value of m. Such a nomograph has been constructed, and is shown in Fig. 3.

To use the nomograph, one first computes $n\tau_1$ and $n\tau_m \equiv n(\tau_2 - m\tau_1)$ for one of the values of $m = 2, 4, 8, 16$ or 32. The value of $n\tau_1$ is located on the first line of the nomograph, and the value of $n\tau_m$ on the line of the third set appropriate to the selected value of m. A straight line connecting these two points gives the value of f_m on the appropriate line of the second set.

To illustrate the use of the nomograph, suppose a scale-of-8 pre-scaler having an input resolving time of 10^{-7} sec precedes a conventional scaling circuit having a resolving time of 5×10^{-6} sec. With a counting rate of 10^5 per sec, $n\tau_1 = 0.01$ and $n\tau_8 = 0.42$. The nomograph shows that the counting loss of 1% is due almost entirely to losses at the input. With a counting rate of 10^6 per second, $n\tau_1 = 0.1$ and $n\tau_8 = 4.2$, and the nomograph now shows that the counting loss due to τ_1 alone is 9.2%, that due to τ_2 alone is 3.8% and that due to both is 12.3%. From this illustration, it appears that there is little justification for using more than a scale-of-8 for a pre-scaler if its input resolving time is as great as 10^{-7}. To satisfy the criterion $\tau_2 = m\tau_1$ for no possible counting loss at the input of the conventional scaling circuit, the pre-scaler would have to have a scale of fifty.

As a final example, we shall obtain

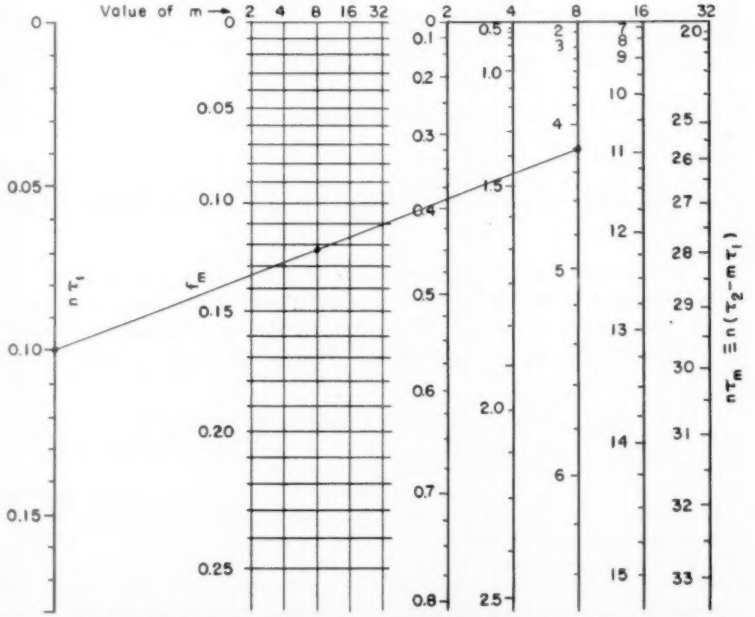

FIG. 3. Nomograph for computing the fractional counting loss f_m when a nonextended resolving time τ_1 exists at the input of a scaler, and a second nonextended resolving time τ_2 exists after a scale-of-m. The rate of occurrence of pulses at the input is n

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the fractional counting loss for the case first discussed by Alaoglu and Smith (3), which differs from the case just treated in that τ_2 is an extended resolving time. The observed counting rate is the area under the unnormalized density curve $p_m^{**}(t)$ given by Eq. 40, times the counting rate n_m at the output of the mth scaling stage (*Cf.* Eq. 23). This latter counting rate is found by expanding $P_m^*(s)$ (Eq. 25) in powers of s, *i.e.*,

$$P_m^*(s) = 1 - s\,[(m/n) + m\tau_1] + \cdots$$

giving $\overline{t_m} = (m/n) + m\tau_1$, or the counting rate

$$n_m = \frac{n}{m}\,\frac{1}{1 + n\tau_1} \tag{44}$$

Accordingly (for $\tau_2 \geq m\tau_1$) we have the result of Alaoglu and Smith

$$n_{obs.} = \frac{n}{m}\,\frac{1}{1 + n\tau_1}\,e^{-n\tau_m} \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!} \tag{45}$$

giving the fractional counting loss

$$f_m = 1 - \frac{1}{1 + n\tau_1}\,e^{-n\tau_m} \sum_{r=0}^{m-1} \frac{(n\tau_m)^r}{r!} \tag{46}$$

For $\tau_2 \leq m\tau_1$, Eq. 32 gives the value of f_m. Alaoglu and Smith show how the incomplete exponential series occurring in these expressions are related to the incomplete gamma function, which has been tabulated.

* * *

The author is greatly indebted to the Research Corporation for supporting his research program of which the work reported here forms a part.

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Radiochromium Plating for Friction Studies

The application of radiochromium to piston rings is another instance of the successful use of radioisotopes to study the phenomena of friction. The plating technique described here could be applied to research on other machine parts as well.

By JOHN T. BURWELL and S. F. MURRAY

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ONE OF THE ANSWERS sought in friction studies is to what extent friction during sliding is due to the making and breaking of very minute adhesions or "welds" between the two surfaces involved. Well suited to this problem are radiotracers because of their great sensitivity and ease of detection without destroying the sample.

Briefly, the procedure is to make one of the surfaces radioactive, carry out the friction experiment, and then examine the other surface for evidence of radioactivity. Its presence indicates

that very minute amounts of material from the first surface have been left adhering to the second surface after sliding.

The method can easily be made quantitative to determine the dependence of the amount of this transferred material on such factors as load, speed, lubricant, and composition of the two surfaces. An earlier paper* outlined procedures for the various steps in the method such as activation, friction run, detection, and calibration.

One of the methods of making the first surface radioactive is to plate it with a thin layer of material containing the active isotope. This method is useful when studying a standard item of machine equipment which is already manufactured, and which is unsuitable because of size or shape for direct irradiation in a cyclotron or neutron pile. One such item is the piston ring† in an internal combustion engine. Its friction and wear against the cylinder wall is of great interest to the engine designer and manufacturer.

Piston-ring Research

The plating of piston rings with wear-resistant coatings is a subject that is receiving considerable attention these days. One of the most practical and successful of such coatings is chromium. Therefore, as one aspect of this problem, a study was undertaken to determine the tendency of chromium-plated piston rings to transfer metal to the cylinder walls during operation in a single-cylinder test engine, using the radiotracer technique. The method and problems encountered in plating with radiochromium are reported here.‡ While the method was applied in the present work to the plating of piston rings, it could equally well be applied to other machine parts, and to experiments related to other phenomena such as solid diffusion, *etc.*

The principal problem in the method is as follows: Radiochromium is most readily available in the form of metallic chromium as furnished by the Oak Ridge National Laboratory, under the approval of the U. S. Atomic Energy Commission. But, the usual chromium plating solutions are made from chromic acid, CrO_3, in which the chromium has a valence of +6. (It might be possible to have CrO_3 irradiated directly in the neutron pile so long as it did not decompose, but this would require special handling whereas the metal containing radiochromium can be supplied directly from stock.)

There are a number of chemical methods for converting metallic chromium to CrO_3, but most of them leave reaction products that are not easily separated from the CrO_3, and interfere seriously with its plating satisfactorily. In fact, it was found that chromic acid solution will not plate satisfactorily in the presence of any foreign material except a very small amount of one of the other oxidizing acids, such as sulfuric acid.

Radiochromium Plating Procedure

At the suggestion of Prof. J. W. Irvine, perchloric acid was tried as the oxidizing agent for raising the metallic chromium to a valence of +6, because it was hoped that in this process all of the residual products could be driven off by heating. The procedure used follows:

A 1.1-gm sample of radiochromium is dissolved in a 200-ml round-bottom condenser flask using about 100 ml of 30% perchloric acid in water. A hot plate is used to aid in the process of solution. The flask and contents are then clamped to a vertical rod, a ther-

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* J. T. Burwell, NUCLEONICS **1**, No. 4, 38 (1947).

† Since this work was done, it has become possible to irradiate certain sizes of piston rings in the Oak Ridge pile.

‡ Complete results of these studies are to be published by the Institution of Mechanical Engineers, London.

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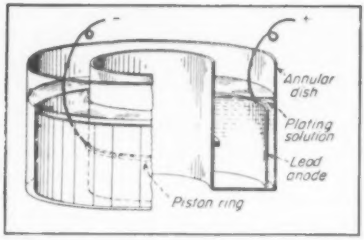

FIG. 1. Sketch of annular dish for the plating bath with lead anode and piston ring in place

mometer is inserted loosely in the flask, and the whole assembly is placed in a hood.

It is necessary to use caution in handling perchloric acid, since the acid, when hot and concentrated, reacts violently with organic matter. The hood should be clean of any organic residue adhering to its sides, and should be large and well ventilated.

A bunsen burner is used to heat the flask, and the temperature is raised to 200–205° C over a period of from 15 to 20 minutes. Water distills off first until a temperature of 203° C is reached. At this point concentrated acid of composition $HClO_4 \cdot 2H_2O$ begins to pass over at constant temperature. The trivalent chromium solution becomes oxidized to chromic acid by the concentrated perchloric acid, and it settles out as a dark red precipitate. The temperature should be held at this point for a couple of minutes to ensure complete oxidation; after that the flame is removed and the flask allowed to cool.

The excess perchloric acid is then removed by filtering through glass wool held in a funnel. The chromic acid which remains in the condenser flask, and that which is trapped in the glass wool, is then redissolved in as small an amount of water as possible, and retained in a weighed beaker. The beaker is placed on a low-temperature hot plate to dry slowly. This drying process takes about two days, and while the last of the perchloric acid which remains is fuming off, the residue should be stirred frequently to prevent the partial reduction of the chromic acid. The dry residue is left on the hot plate for about two more days to ensure complete dryness, since perchloric acid interferes with the plating procedure.

The beaker and its contents are again weighed, and enough inert chromic acid is added to make up 7.5 gm of the salt. This step is necessary to obtain a plating solution that is concentrated enough to ensure a good deposition of chromium. The chromium acid is then dissolved in 100 ml of water, with 0.14 ml of 6*N* sulfuric acid added as a catalyst for the plating bath. For best results, the ratio by weight of chromic acid to catalytic acid radical expressed as sulfate ion should be about 100 to 1.

A typical chromium bath can be made up as follows:

Chromic acid	1,000–1,500 grams
Sulfuric acid	10–15 grams
Water	(Sufficient to make one gallon—3.79 liters—of solution)
Temperature	60–65° C
Current density	1 to 2 amperes per square inch

This solution gives what is known commercially as a "hard" plate, and is said to have a cathode efficiency of 13%.

A lead anode should be used since the high oxygen overvoltage at the anode helps to prevent the rapid reduction of the chromic acid to trivalent chromium.

To keep the volume of the plating solution at a minimum so that the quantity of inert chromium to be added as explained above will be as little as possible, the plating of the ring should be done in an annular-shaped dish. If such a dish cannot be specially made, two evaporating dishes, one placed symmetrically inside the other, will serve very well. The ring is placed around the outside of the inner dish and the lead anode is placed concen-

trically around it, fitting just inside the outer dish. Provision for electrical connection to the ring is best made by soldering a copper wire to one of its sides.

For these experiments in which the rings used had a diameter of 3¼ in., a radial thickness of ⅛ in., and a face width of 1/16 in., 100 ml of solution gave satisfactory plating. The general arrangement is shown in Fig. 1.

The piston rings used in this work were cast-iron with a chromium-plated surface that had been applied by the manufacturer. They were cleaned with emery paper, dipped in benzene, rinsed with alcohol, and then placed in position. When all electrical connections had been made, the solution was poured into the plating bath. The rings were plated for 15 minutes, removed and rinsed, and then replaced and plated for 15 more minutes, using a current density of 6 amp per sq in. The temperature of the solution was held at 70 ± 5° C by means of a water bath. This is slightly higher than the recommended range because the concentration of the chromic acid bath was below the recommended concentration for typical plating solutions.

It was difficult to estimate the actual thickness of the chrome plate because the efficiency of the plating solution was not known directly. However, differential weighing of the ring suggested that it was approximately 0.0014 in. thick, although the weighing method seemed rather doubtful in its accuracy. If correct, this would correspond to a plating efficiency of only 3%.

Test Results

One or two of the results of the tests with these rings may be of interest. The three compression rings were plated in this manner with radiochromium and run in a single-cylinder internal combustion test engine (CFR) under normal operating conditions. After the run, the cylinder was removed from the engine, carefully degreased, and the steel wall scrubbed with solvent using cloth rags and waste. A photographic film was inserted in the barrel and exposed for 48 hours. See Fig. 2. The direction of piston travel is vertical with the top of the chamber toward the top of the page.

FIG. 2. Autoradiograph of chromium metal transferred to cylinder barrel of CFR (Cooperative Fuel Research) engine from three chrome-plated piston rings after running under normal operating conditions. (Contrast on photographic print was artificially enhanced.)

The small white specks in Fig. 2 are the transferred chromium which adhered to the steel barrel and could not be wiped off. The vertical line on the left is actually a pair of close parallel lines from the tips of one of the rings at the gap which apparently happened to remain in this one position for some time.

There seems to be most transfer near the upper limit of the ring travel. Presumably this is because there is the least amount of lubricant present in this region and the chromium remains adhered in spite of the rather severe temperature and oxidation resulting from combustion which takes place in this region.

* * *

The authors are indebted to Grace Anderson for assistance in the chemical work. The engine investigation was carried out by C. D. Strang.

This work is part of a program of research supported by the Chrysler Corporation.

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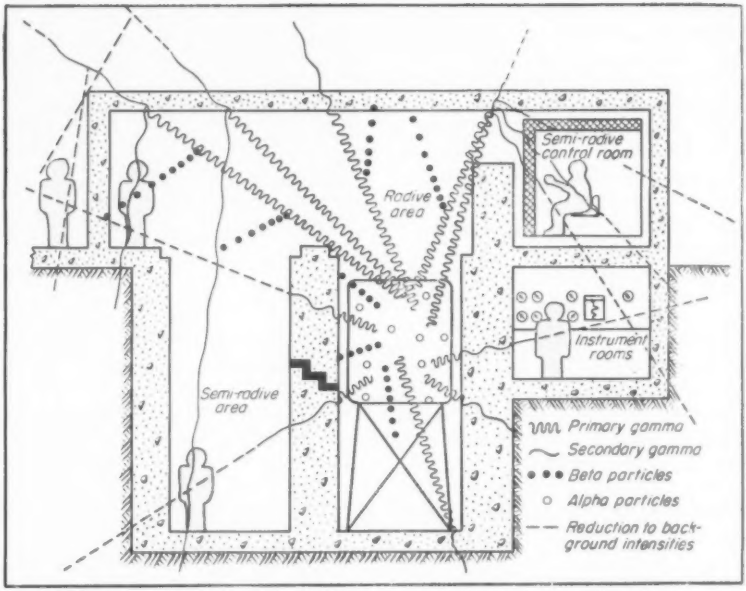

FIG. 1. Distribution of radiation in a radiochemical processing plant

INSTRUMENT NEEDS of the Radiochemical Processing Plant

By V. L. PARSEGIAN

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THE ECONOMIC FEASIBILITY of nuclear power will probably be determined in substantial measure by the economics of the chemical processes associated with nuclear reactors. The facilities required to process uranium ore and enrich its U^{235} component in preparation for use in a reactor are large and complex. When one adds to these the facilities required to process plutonium, unconsumed uranium, or the fission products, the combination tends to dwarf the reactor itself, both as to size and operating expense. It is important therefore that the instrumentation of these chemical facilities make their operation as efficient as possible.

The techniques used in such chemical facilities, of course, differ from the practices current in more conventional chemical industries. In one important respect, however, the new production processes should emulate the practices of the older industries if they are to be

successful, namely, in the attainment of automatic control of product quality and output. And as the volume throughput increases to large proportions, it becomes economically feasible and necessary to adopt continuous-flow operation for an increasingly larger portion of the chemical cycle. Automatic operation of such a system is possible only when there is a well-integrated relationship of instrumental methods associated with the process.

For example, the explanation for the successful production schedules of the modern petroleum refineries is to be found to large degree in the well-organized instrument control systems and in the process engineering that makes use of these instruments. Indeed, the petroleum industry attained economic success only after it had substituted a good measure of automatic control and continuous-flow throughput for the old soup-ladle batch methods of refining. The advantages of automatic control for production-scale operations in improving uniformity of product, by reducing the required personnel and human errors, cannot be easily overestimated.

The chemistry of the radiochemical process does not differ markedly from that of conventional chemical plants. Thus there is also the need for the measurement or control of temperature, pressure, flow rate, liquid level, specific gravity, hydrogen ion concentration, and other variables. There is, however, one additional variable, namely, the presence of radioactive materials, which makes the design and operation of radiochemical plants drastically different from the others. Where an operator could once reach his hand to turn a valve at the tower, or observe at close range a faulty flow meter, he must, in these newer plants, operate these units remotely, from behind the protection of heavy walls. But just as improved techniques helped to overcome the hazard of gasoline and explosives production, it is expected that new techniques will be devised to overcome the obstacle of radioactivity.

Radiochemical plants will undoubtedly undergo major changes in design in the course of the next few decades. Because of the nature of their operations, these changes are likely to be intimately dependent on instruments and instrumental methods that remain to be developed. Such development will not be easy to effect, and a review of the problems and characteristics desired of these instruments may aid instrument manufacturers to contribute more effectively to this new industry.

CONVENTIONAL PLANT NEEDS

The primary function of a production plant obviously is to produce a product in quantity and as cheaply as possible,

Much needs to be done to meet the instrumentation requirements of radiochemical plants. The author, who is with one of the foremost companies in the nuclear engineering field, presents valuable information to guide manufacturers interested in developing such instruments. He discusses:

1. *Instrument design and performance characteristics*
2. *Principles of measurement useful in these new instruments*
3. *The value of radiation measurement as a useful tool in analysis and control of the radiochemical process*

In his discussion, the author emphasizes the similarity between the operation of a radiochemical plant and that of a conventional chemical plant.

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while maintaining product quality within carefully defined specifications. In the petroleum refinery the "chemistry" of the process is complex, and becomes increasingly so with demand for improved gasoline and its multiple by-products. The more exacting the specifications are made regarding product quality, the more carefully does the entire process have to be maintained at optimum efficiency, and the more sensitive the measuring and control systems must be to detect and correct "off-spec" conditions.

When gasoline of high octane value is the goal of a particular refinery, it would seem that an instrument for measuring octane rating would be the most important instrument of that refinery. Unfortunately, there has been no such instrument available to the industry. Even a mass spectrometer or an infrared absorption analyzer, were they altogether suited to plant-monitoring operations, would scarcely suffice to define in easily measurable terms the complex specifications associated with gasoline rating.

Since direct measurement of product quality or composition cannot be made, the industry has had to make almost exclusive use of secondary variables which indicate or influence product quality. In the petroleum refinery these have been principally temperature, flow rate, pressure, and liquid level, in roughly decreasing order of importance. These particular variables have been of most interest because:

a. The process is sensitive to changes in these variables, and their measurement and control can be effected with instruments that are fast in response, sturdy, and suited to plant conditions.

b. These same variables and their measurements are easily adapted to automatic control of a continuous-flow system.

To make these secondary measurements effective, the process engineer first had to determine the optimum conditions of temperature, flow rate, pressure, and liquid level that would assure product quality. It was necessary to establish the effect of changes in these variables on process characteristics and product quality, under representative dynamic conditions, so that every departure from optimum performance could be restored quickly and without overshooting.

The job had its difficulties. Temperature differences required for fractionation were sometimes too small to be controlled accurately, and unusual devices had to be resorted to. The industry came to depend more on sensitivity and reproducibility of measurements than on absolute accuracy. For example, measurements taken in the refinery with potentiometric instruments and thermocouples ordinarily permit sensitivity to temperature changes of perhaps 1° F or even less. But the thermocouple is usually encased in a heavy protection tube, and an instrument reading of, say, 800° F would be scarcely more than an arbitrary reading in an oil stream wherein the local temperature gradient might easily exceed 30°. The significant requirement, as far as process efficiency in the plant is concerned, is usually not the knowledge of the absolute accuracy of the temperature but the maintenance day after day of a temperature which is found to give proper results.

Simultaneously with process development, the oil companies made earnest effort to improve the available instruments and to study more carefully the theory of automatic control. The separation processes were studied under dynamic conditions, with attention to time constants and variables both of the controlling instruments and of the process. Assisted by the instrument companies, the travail continued for years until the instrument field generally took on a new look. Central instrument rooms were installed in the

refineries, to accomodate a multitude of recorders and controllers, and facilities to permit systematic central checking of process performance by inspectors and operators. The instruments themselves attained a high degree of reliability, accuracy, speed, flexibility, ease of adjustment, standardization of components, and easy replacement of components.

The technique of the oil industry has changed radically with the years; but whether the refining was accomplished by the use of distillation shells, fractionation towers, thermal or catalytic cracking, polymerization, or solvent extraction, the same dependence on simple measurements and close control of temperature, flow rate, pressure, and liquid level has predominated and given successful results. This success has been possible despite the great complexity that arises from variation in the composition of the natural crude oils.

This statement is not intended to imply that mass spectrometers or other more complex methods will not eventually provide the better answer to automatic control. On the contrary, the newer separation processes require such difficult identification and control of variables that the oil industry is earnestly attempting to develop analytic instruments which might be better suited for operation in the plant. The analytic laboratory of the refinery serves a very important part in the process monitoring of the refinery, and these laboratories often depend on the mass spectrometer, infrared absorption measurements, Raman spectral analysis, and the like. Possibly nuclear engineers will be able to adapt these analytic instruments for control purposes in their plants before the oil industry will have adopted them. Indeed, the K-25 gaseous diffusion plant at Oak Ridge, in which uranium is enriched in its U^{235} component, was the first large production plant to make use of the mass spectrometer as a process monitor.*

The lesson to be learned from these older industries for application to the nuclear field is that although good analytical instruments can contribute much to automatic control, satisfactory control *can* be attained by the use of simple, dependable measurements of secondary process variables.

THE RADIOCHEMICAL PLANT

The radioactivity that exists in any particular chemical plant associated with the nuclear field depends on the activity of the material being processed. The intensities that develop in the neighborhood of process vessels containing fission products may easily reach many roentgens† per hour, the larger part of which is due to gamma rays, whereas the processing of raw materials involves much lower activities. When one considers that the maximum permissible dose for operators is usually below 0.3 roentgen per week—a factor of almost several thousand smaller—it is apparent that a severe hazard exists when fission products are present in a plant.

Such plants can usually be divided into two areas (see Fig. 1); all the radioactive materials can be contained in a restricted radive‡ area by heavy shielding, leaving the remaining area safe for continuous occupancy. Sometimes an intermediate or semi-radive area may be designated wherein limited occu-

* A. O. Nier, *et. al.*, Recording Mass Spectrometer for Process Analysis, *Anal. Chem.* **20**, 188 (1948).

† For our purposes, a roentgen may be defined as that quantity of radiation which develops 2.08×10^9 ion pairs in a cu cm of air under normal conditions of pressure and temperature.

‡ The word *radive* has been proposed by W. B. Snow of The Kellex Corporation [see NUCLEONICS **5**, No. 6, 75 (1949)]. It may be used to indicate qualitatively the presence of nuclear radiation (or of radioactive materials) in such intensity (or concentration) as to offer exposure or ingestion hazards to personnel. Possibly it can substitute for the word "hot" which is becoming all too confusing in the language of the nuclear engineer.

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pancy is permitted for the routine performance of specific tasks such as maintenance work, sampling, or the like.

This paper will emphasize the needs of radiochemical plants in which the activity is high, both because of the importance of such plants to a reactor and because of the greater severity of their instrument problems.

In a plant containing high radioactivity levels, the offices, instrument rooms, and rooms containing nonradioactive chemicals are located in nonradive areas. Process vessels and interconnecting pipes containing radioactive materials are restricted to the radive areas. Dividing the two is a complex system of heavy-walled shields, many feet thick, which forms a nearly impenetrable barrier to the passage of radiation from the radive into the nonradive or "safe" areas.

Although the instruments and panels are located in the instrument room, the detector elements and valves often must be placed in close contact with the radive vessels and pipes, where they are exposed to the full attack of the radiation. These detectors and valves, once installed, may not usually be touched again by human hand if they find contact with radioactive fluids. They must perform their function well; if they should fail, as detectors are wont to do, they are removed from service by remote-handling mechanisms, and given special disposition because of the difficulty of "decontaminating" components that have been in contact with radive fluids. The replacement unit must be installed by remote-handling devices, and be calibrated without the "personal touch" which conventional plants find important. Throughout the replacement procedure, conditions should permit the operator to complete the job without overexposure, and without requiring close timing so as to prevent overexposure.

This description emphasizes two characteristics which instruments must have when they are associated with highly radioactive processes, namely, that they be capable of transmitting intelligence by telemetering, and that they permit maintenance by remote-handling mechanisms.

Within the plant there is the need for a variety of measurements, similar in many respects to the refinery from which we sought example. The ultimate goal is again automatic control of the process, perhaps with continuous-flow throughput if the volumes are large. (It may be well to add the factor of inventory cost when expensive process materials are involved. Continuous flow may become feasible at an earlier stage if it thereby reduces inventory costs.) The process itself is again influenced by a host of variables, such as temperature, flow rate, acidity. Some of these are maintained at fixed values, while others are made control variables. Monitoring instruments suited for analysis of product streams again are generally unavailable, and liberal recourse has to be made to secondary measurements and close controls to maintain process efficiency and quality of output. Moreover, these functions must be provided with means for telemetering and remote maintenance!

Although the presence of radioactivity severely complicates the problem of instrumental measurements, there is one aspect of it that is an advantage, namely, the fact that radioactivity of the stream is a measurable and frequently important variable of the process. For example, when one is concerned with the problem of removing the intensely radioactive fission products, *i.e.*, decontaminating the solution, measurement of radiation intensity can accurately trace the decontaminating efficiency and changes in the process along every step. Thus, the presence of nuclear radiation presents both a problem and a very useful tool. Un-

fortunately, this advantage has not often been exploited, for reasons which will be discussed presently.

Radiation measurements in the radiochemical plant may be divided into two, or possibly three, classes. In the first class are the health physics measurements of radiation. These measurements involve intensities at various levels ranging from background (about 0.02 mr per hour) up to many times background; their purpose is to assure that radiation or radioactive materials remain safely contained. Among these measurements are those in which film badges or pocket dosimeters are used for personnel monitoring to determine the total exposure of the individual, and ionization chambers are used to measure the activity in the air, in certain radive areas of the plant, and in the neighborhood of nonradive benches, *etc.*

The measurements of the second class may be at intensity levels ranging from background up to very high intensities, their purpose being to measure the activity of the process streams within pipes or vessels. These measurements may inform the operator when the separation efficiency has changed, when the activity is excessive within certain streams, or to serve as alarm or safety devices against accidental diversion of radioactive fluids.

Sometimes sampling measurements are listed in a third category, whereby the hazards of radioactivity are reduced by drawing samples from the process stream into an area where analysis may be performed with fewer handicaps. The sampling methods may take any of several forms, ranging from batch to continuous-flow devices, and the activities again range from close to background up to dangerous levels. This will be discussed in a later section.

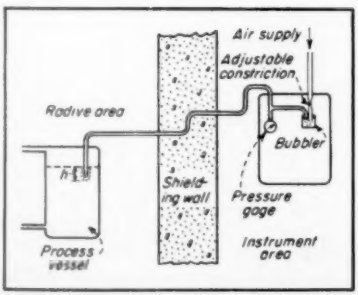

FIG. 2. Pneumatic telemetering system for liquid level measurements

TELEMETERING SYSTEMS

Measuring Systems

What are the characteristics of a safe or preferred telemetering system? As observed previously, all measurements and other intelligence originating at the detectors in the radive areas must be communicated by telemetering devices, through a system of shielding walls, to instruments which are usually mounted in rooms located many feet away. The operator has ready access to the instrument panel, but "uneasy" or no access to the detector system. Telemetering may be accomplished by mechanical coupling, pneumatic or liquid system, electrical or electromagnetic system, optical device, or by some combination of these means. The most important requirement made of such devices is that they do not under any reasonable set of circumstances permit the passage of radioactive materials from the radive to the safe areas. In view of the importance of this requirement, it would be well to compare the merits of these several telemetering systems.

Mechanical couplings involving long distances and circuitous routes usually suffer from relatively high inertia, frictional losses and mechanical free-play, which render the whole system insensitive except when large forces and large movements are involved. Sometimes one cannot altogether circumvent a shield with such couplings, but must compromise by passing mechanisms

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through breaks in the shield system, thereby offering a possible path for the entrance of radioactive gases or fumes except when unusual seals are used.

Pneumatic systems are very common in industry, particularly in process applications. In one application, air is passed through a constriction and bubbler system (Fig. 2) and a pipe system that passes through shielding walls, into vessels in the radive area. The air emerging from the pipe into the process fluid must attain a pressure sufficient to overcome the head of liquid, and the gage pressure increases as $h\rho$ is increased (ρ = density, h = height of liquid above tube opening) permitting a measure of $h\rho$ by measuring pressure changes.

The system as shown has a number of disadvantages, of which a few may be mentioned to illustrate the problems of these applications:

1. The air pipes make direct connection from the instrument rooms to the radioactive fluids in the vessel, and an increase in pressure in the vessel, or failure of the air supply, could seriously contaminate the instrument room. (A check valve system for stopping the flow of fluid in the reverse direction would not be considered overly safe.)

2. Even without air failure there is likely to be slow diffusion of radioactive vapors from the vessel along the air tubes and into the instrument, unless the air flows at a sufficiently fast rate to "wash" the air pipes. The trickle rate of air flow common to these measurements would scarcely be sufficient to wash the air lines.

3. The passage of air lines through the shielding wall as indicated in Fig. 2 reduces the effectiveness of the shield to at least half its value along the axis of the pipe. This effect can, of course, be minimized by using small diameter pipes, by increasing the number of bends in the pipe, or preferably by running pipes around the shield in suitable galleries.

The first two faults are the more serious and emphasize the need for avoiding direct contact of the air with radioactive fluids. This point will be emphasized in another connection.

If the air were to discharge through orifices directly into the atmosphere of the room in which the radive vessel is located, or if there were dependable separating media between the air supply and the radioactive fluids, the principal objections to pneumatic systems would be eliminated. Pneumatic systems have been well developed for process applications and possess certain advantages of performance and simplicity. For these reasons, their use should not be discouraged, particularly if provision is made to separate the air stream from the radioactive fluids, say by the use of intermediate compartments or diaphragms containing nonradioactive liquids.

Electrical or electromagnetic systems do not suffer from these serious objections, since connecting wires may usually be run along channels which may be well-sealed against transmission of fluids. For this reason, they perhaps ought to be given increased emphasis and some preference in the development of new systems, other factors being equal.

Another advantage of electrical systems arises from the fact that quite a few useful detector elements are electrical units which may be connected directly to the bridge or null-balance instrument circuits. Changes of inductance, capacitance, resistance, electrical current or voltage, may be measured quite conveniently. Servo systems offer similar advantages for detection of movements.

Combination telemetering systems sometimes offer advantages. For example, by the use of an air-electric relay whereby air pressure changes may be developed proportional to an electric current, one can have facility in controlling a pneumatic system within a radive area by means of an all-electric system at the control panel.

In this connection it may be well to point out the fact that these pneumatic systems should be supplied with clean

dry air to avoid the usual failures of pneumatic systems. This of course adds to the cost of operation of pneumatic systems.

Systems for Remote Manipulation

Remote manipulation is necessary for valves, maintenance tools and wrenches, and operations on inaccessible objects. Much of the discussion of measuring systems may be applicable to manipulating systems as well, the principal difference being that larger forces and human control are frequently required for the latter operations.

Remote maintenance of plant components requires that the operator view his every operation. There exists a serious problem of viewing of operations within the radive areas from behind shielding walls. In this connection there is need for the development of binocular optical systems, television methods and transparent shielding materials. The relative value of such methods is determined by the degree of naturalness of vision which they afford, including depth perception and resolution of adjacent parts, by the flexibility and ease with which they may be manipulated for the sighting of various operations, by the ease with which operators may be trained, by their dependability in dealing with difficult or unexpected situations, and by the protection they afford the operator against exposure to radiation.

A great deal needs to be done to develop simple mechanical movements and particularly servomechanisms with which forces can be transmitted in a controlled manner to remote objects. In developing devices for the remote manipulation of wrenches, one should simulate the action of one's own hands and fingers as far as possible for applying force or transferring objects over distances. The training of operators for remote manipulations is difficult but can be greatly simplified by reducing the inertia of the system, and particularly by making use of movements which are natural to them from their automobile experience and everyday habits.

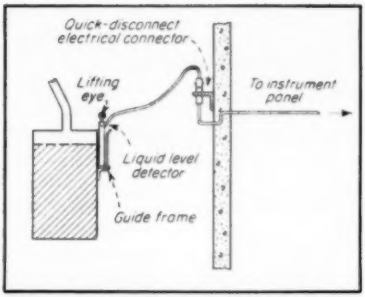

FIG. 3. Illustrating principles of a liquid-level detector system which permits easy replacement

DETECTOR ELEMENTS

Important as the foregoing telemetering considerations are, they may be overshadowed by the advantages or disadvantages which the detector elements themselves offer in the selection of any particular instrument system. The remotely controlled manipulations required to replace detector elements associated with radioactive vessels are at best awkward, and often troublesome to the point of requiring plant shutdown. Probably the most important instrumental advances have to be made in the development of detector elements.

What are some of the characteristics particularly desired in detectors for these plants? In roughly decreasing order of importance, one might list the following:

1. Long life. The importance of long life without maintenance is apparent. Its importance increases in proportion to the difficulty with which a detector element can be replaced. If it can be replaced with only moderate difficulty, a two-year life can be considered to be reasonable; if the process vessel has to

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be taken apart to replace it, a ten-year life would be a better goal for instrument design purposes.

2. Replaceability. Since instrument components do fail, it is important that they be replaceable easily and without loss of accuracy, and without requiring process shut-down.

Detectors that are "replaceable" are those that do not require intimate contact with the process streams (Figs. 3, 4). For example, a thermocouple or resistance thermometer can be placed in a protection tube within the process vessel, and can be readily replaced without disturbing the process stream. A flowmeter of the conventional orifice type, on the other hand, requires disassembly of the process line before it can be replaced.

A further advantage of a detector unit which is not in contact with the stream arises from the fact that the unit removed from service will not have accumulated serious radioactivity, since radioactive contamination develops largely as a result of contact with radive fluids in these plants. The disposition of used components therefore presents a less serious hazard and problem.

3. Standardization and checking. It is important that detector elements permit some form of periodic check of standardizations from the instrument panel. This checking may be permitted to require a series of successive steps as by pressing a series of buttons to introduce increments of change by relay action, but it should not be required oftener than once each day.

4. Simplicity. Considerable complexity can be tolerated in an instrument system so long as the detector element remains simple and the complex components are restricted to the instrument panel area.

5. Stability. Instruments should continue in operation and maintain their calibration to within ±1% of

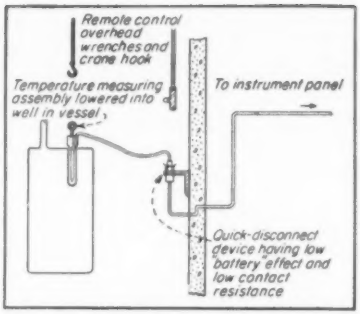
Remote control overhead wrenches and crane hook
Temperature measuring assembly lowered into well in vessel
To instrument panel
Quick-disconnect device having low battery effect and low contact resistance

FIG. 4. Temperature measurement by thermocouple or resistance thermometer, sealed from radive fluid, with quick-disconnect device

range when they are subjected to line voltage variations from 115 volts ranging from 95 volts to 135 volts; they should also withstand ambient temperature changes ranging between 50° F and 120° F, and relative humidity up to 100%. Very little attention has been given to testing radiation-measuring instruments against these conditions.

6. Sensitivity. It was pointed out earlier that chemical plants have learned to depend on sensitivity and stability more heavily than on absolute accuracy to maintain automatic plant operation. A sensitivity of ±1% of range is common and satisfactory, while ±0.5% or 0.1% would have some advantages.

7. Adaptability to automatic control. An instrument system which automatically feeds into an output meter or recorder obviously will be far more useful in a production plant than will an instrument which requires manual adjustment and eye observations for each reading; the motion of an indicator or of a recording pen can very easily be made to initiate an alarm or to provide automatic control. (It may be noted that most automatic controls for the radiochemical plant are likely to be of the proportional type, without too much need for "derivative-control," "pre-

act" or the like, for the time being.) In some respects this item perhaps ought to be given a higher order of importance. An important requirement of controllers is that they "fail safe," or prevent serious damage to product or personnel if the instrument should fail as a result of power failure or instrument breakdown.

8. No moving parts. It is almost axiomatic that elements containing moving mechanisms are more prone to failure than are nonmoving devices.

9. "Packaged" units. Both the detector element and the major instrument components should be "packaged" to permit easy testing and quick replacement by relatively unskilled personnel. This is not meant to encourage the use of conventional plug-in devices, for reasons that will be discussed later. In this connection we might also emphasize that instrument components should be interchangeable without requiring special selection or matching during assembly and test.

10. Resistance to corrosive fumes. To this may be added dust-proofing and explosion-proofing.

11. Ruggedness against difficult plant handling and storage conditions.

12. The value of **absolute accuracy** depends on the application; in most applications an over-all absolute accuracy of measurement of $\pm 5\%$ of total range is satisfactory, while $\pm 1\%$ would be considered extremely good. Similarly a time constant or time lag in the response of a detector element amounting to 30 seconds (to reach 90% of final response change) is satisfactory when process monitoring is involved, whereas alarm devices should be operated within a fraction of a second.

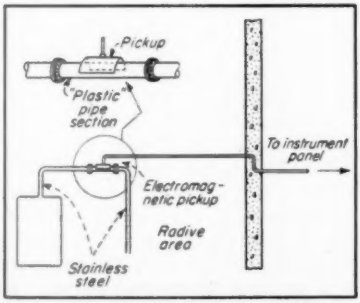

FIG. 5. Illustration of the use of a permanent non-conducting pipe section to permit detection of changes of electromagnetic phenomena in process fluid

DETECTION METHODS

Considerable emphasis has been given to the importance of detector elements that do not require contact with radive fluids. What are some of the physical principles that may be useful in developing such detectors?

To begin with, the process fluids may be either in large vessels, say of several feet in diameter, or in pipes. The vessels and pipes usually are made of stainless steel. In order to make use of electrical methods of measurement, it is often possible to substitute a nonconducting section, say of a plastic such as Teflon, for a section of vessel wall or pipe to prevent short-circuiting of the electromagnetic field by the metal pipe (Fig. 5). The plastic section would thereafter be an integral part of the pipe section and left unmoved when the instrument components are replaced.

The process fluids within the vessels on which measurements are to be made may be water, organic solvents, solutions containing fission products or a large proportion of heavy-atom compounds, and have specific gravities ranging from below 1 to well above 2. They may be colorless or heavily colored, may range from highly transparent to opaque, and can vary with time as process conditions change. Corrosion of the vessels may be unavoidable, and corrosion products or other deposits are likely to accumulate on the inside walls of the vessels.

High pressures and high tempera-

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tures are avoided in such systems, and every reasonable effort is made to isolate the components of the system so as to safely contain and limit the effects of any rupture or failure that may develop.

What are some of the fluid characteristics that are likely to be of interest? Those mentioned in connection with the petroleum refinery are of interest here also, namely, temperature, flow rate, liquid level, and pressure (although pressure measurements in this connection involve small magnitudes and are frequently associated with the measurement of specific gravity and liquid level). Hydrogen ion concentration, radioactivity, and fluid composition are the remaining items of major interest, the last including a host of variations.

Temperature Measurement

Fortunately, it is possible to isolate thermocouples, resistance thermometers, or other temperature-sensitive elements from direct contact with the radive fluids by means of protective tubes. These elements can therefore be replaced readily without requiring stoppage of the process.

Perhaps the most important improvement needed relating to temperature measurement is the development of a simple connector which will expedite replacement of thermocouples and extension wires without requiring soldering or the use of screws (Fig. 4). A self-aligning connector is needed which can be readily assembled or disconnected by simple lever motion, and is capable of withstanding corrosive atmospheres for a period of several years. Under such conditions it must not develop a voltage due to "battery" effects of greater than 15 microvolts when used with thermocouples, or, in addition, contact resistance exceeding about 0.01 ohm when used with resistance thermometers. In a choice between the thermocouple and resistance thermometer, the higher accuracy (by a factor of roughly 10) of the latter is offset by its more fragile construction and higher replacement cost, by the greater restriction on the contact resistance of its connector, and by the greater limitation on the length of its extension wires to the recorder.

Flow Rate

The measurement of flow rate presents a serious problem. Conventional instruments usually require passing the fluid through constrictions to develop measurable pressure drops proportional to flow rate. Telemetering usually makes use of moving elements in the process stream. Obviously these methods require that the process flow be stopped and the pipe system taken apart in order to replace units that have become plugged or fail for any other reason.

In another method, fluid flow rate is determined by making use of the heat transport or heat conductivity characteristics that develop temperature differentials along a pipe. For example, when a source having constant heat input is placed against a pipe, the temperature gradients along the pipe in the neighborhood of the source vary in some manner with changes in flow rate. Other combinations, in which the temperature differentials are maintained constant by varying the heat input, have also been attempted, using a number of types of temperature detectors. These efforts have not been as successful as might have been desired.

A disadvantage of this temperature-differential method is that it is likely to require individual calibration of each pipe and fluid system. It has the great advantage that the temperature-sensitive elements need not make contact with the fluid itself. For this reason, it is felt that the method ought to be pursued further, particularly since, for many purposes, one is less interested in accuracy than in reproducibility and

sensitivity, and one can effect automatic control by detecting *changes* in flow rate.

Of the other instrumental methods that have seemed interesting, one devised by Kolin* offers possibilities. In this method (Fig. 6), a magnetic field impressed across a pipe containing flowing liquid develops a potential across probes which are placed in the liquid at right angles to the magnetic field. The potential is proportional to the liquid flow rate. The method could be particularly useful if it were developed to permit performance independent of polarization and effects of corrosion and film on the probes.

One approach to this difficult problem might be to de-emphasize the need for accurate flow rate measurement at difficult points by relying more on other measurements to maintain product quality. Also one might maintain constant pressure head to assure constant flow rate as often as possible. A more promising approach would make use of improved positive-displacement metering pumps whereby the fluid may be pumped at known and controllable rates.

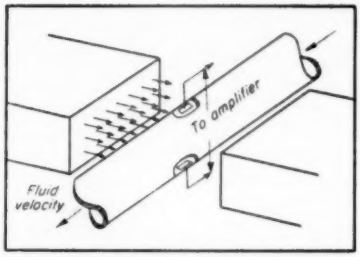

FIG. 6. Principle of the magnetic induction flowmeter [*Note:* Conductivity of the liquid in pipe should be about 100 times greater than that of pipe. When the impedance of the pipe wall is not too high relative to amplifier input impedance, the electrodes may be placed outside the pipe wall. *Example:* With a magnetic field of 2,000 gauss a flow rate of 10 cc/min will produce a signal of about 20 microvolts, dependent upon liquid density, pipe size, and electronic detector circuits.]

Liquid Level

Liquid level can be determined without the use of moving parts inside the fluids, by making use of the dielectric properties of the liquid as measured by a pickup placed *outside* the vessel or special cell (Fig. 3). The method has been used by other industries, but needs adaptation to geometries and fluids of interest in this connection. The measurement and control of liquid level proves useful in controlling flow rates in certain applications.

Other methods will suggest themselves for liquid level measurement in the discussion to follow. The use of radiation measurement will be discussed in a later section. A resistance-measuring device, in which a resistance element dipped in conducting liquid experiences decreasing resistance with submersion, has been frequently suggested but is considered unsatisfactory because it is too much affected by films that might in time short-circuit or insulate the unit. "Nonstickable" floats, the position of which may be determined inductively by coils placed outside the vessel, are useful to consider.

Liquid level measurements may involve ranges varying from a few inches to many feet in different applications. A range of two feet is quite common, involving vessel diameters varying from a few inches to several feet. In general, a sensitivity of $\pm 1\%$ of the range, and an accuracy of $\pm 5\%$ of the range, are satisfactory for most applications.

Pressure Measurements

The importance of pressure measurements results from the fact that flow rate, liquid level, specific gravity, and sometimes solution composition may be determined from such measurements.

Diaphragms or bellows systems which

* A. Kolin, An Alternating Field Induction Flow Meter of High Sensitivity, *Rev. Sci. Instr.* 16, 109 (1945).

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might be sufficiently safeguarded against consequences of failure by a multiplicity of intermediate walls would be interesting to consider for pressure measurements, providing they can be checked and recalibrated remotely against the effects of creep. The fact that very small mechanical movements can vary the reluctance of an electromagnetic circuit by major increments makes relaying of signals from small movements of diaphragms relatively easy. Pressure measurements having sensitivity to changes of one-half inch of water, at a total pressure of up to 50 ft of water are frequently needed. When diaphragm systems are considered for such measurements, the structural strength of the system becomes problematic. Possibly satisfactory pneumatically balanced systems can be developed to meet this need.

Fluid Composition

It is in the determination of fluid composition that one faces the greatest variety of problems and must resort to the most diverse methods for resolving. In the discussion of the petroleum refinery, it was pointed out that progress was made despite the lack of proper product analyzers, the function of analyzing usually being left to the analytic laboratory. Somewhat the same philosophy can be followed in the radiochemical plant, although such a procedure is not considered desirable when it can be avoided.

In attempting analysis for composition, one may follow two lines of attack. In the one, an attempt is made to isolate or distinguish the presence of the individual molecule or atom types, such as by chemical separation, mass spectrometer analysis and the like. This method permits more nearly absolute measurements, but in general is not easy to perform on a continuous basis using presently available techniques and instruments. One might refer to this method as measurement of *primary* variables of the solution.

In the research laboratory, one usually requires absolute measurements of the primary variables or constituents, and is willing to devote considerable time and effort to obtain them. Such measurements will often be dependent for accuracy on the skill of the experimenter, and on the effectiveness of his controls over factors that affect the measurement.

The second method of analysis makes use of *secondary* variables which change with the proportion in the solution of the elements one seeks to identify. The measurement of dielectric properties, density change with concentration, thermal properties and some types of transmission or absorption of radiation, may usually be placed in this category. These measurements assume importance to the analytic laboratory and to the production plant because they are relatively easy to perform, and because detection of *change* in the process offers sufficient information for most purposes. For example, to measure the concentration of metal in solution, one might make use of specific gravity measurements, provided one were able to measure the changes of specific gravity with sufficient sensitivity to detect the desired concentration differences, and provided the effect on specific gravity of variations in solvent composition, temperature, *etc.*, were not overly large. Or the dielectric properties of the solution might be found to offer more specific change with metal concentration.

Various other phenomena might be considered, such as absorption of microwave or longer wavelengths, absorption of light waves ranging anywhere from infrared through ultraviolet, or the absorption of X-rays or gamma rays. One might find resonant absorption at fixed frequencies to be specific to the element, and thus develop such measurements to be an absolute measure of

the atom, or might make use of wider absorption bands which have the nature of secondary measurements.

In any case, the choice of method will have to take into account the following principles:

1. The secondary variable should be easily measurable under the operating conditions to be adopted, and should have a reproducible, single-valued, fairly linear relationship to the primary variable over the range of change to be measured. It should be reasonably convenient to calibrate the measured variable in terms of the primary.

2. The selected measurements should be specific to the primary variable, and not be disturbed overmuch by other variables or changes in ambient conditions.

3. In general the most useful secondary measurements are those that automatically register on a meter, since the signals may thereby be readily connected to a recorder or controller.

How may one know what secondary measurements are adaptable to determine the composition of a particular fluid? One might make use of published information on absorption or physical properties of certain fluids; unfortunately this method is not likely to be very helpful because the required information is not readily found in literature, and recourse will usually have to be made to experimental testing. At some future date it may be possible to pass fluids through a series of routine tests whereby the more important characteristic properties of solutions can be easily identified, but such equipment and routine do not exist at the present time. For the time being one will have to depend on a measure of calculation, good "hunches," and experimental testing.

If absorption or scattering of nuclear radiation are found to be useful for analytic purposes, one may make use of the constant characteristics and small size of a naturally radioactive element such as radium to produce neutrons or gamma rays. The use of X-rays in inaccessible areas is discouraged because of the size and complexity of X-ray equipment, even were the problem of constancy of beam intensity overcome by null-type or comparison-type measurements.

In selection of the type of secondary measurement to be adopted, attention should be given to the preferred characteristics listed under detector elements and telemetering systems.

Perhaps the most useful instrument for analytic purposes in a radiochemical plant would be a mass spectrometer capable of analyzing nonvolatile liquids and solids on a continuous basis. The fact that traces of compounds, and isotopes, must often be identified increases the importance of the mass spectrometer.

REMOTE SAMPLING TECHNIQUES

The instrument problems discussed in this paper are severe largely because of the difficulty of manipulating instruments in the highly radive areas. The problems would be less severe if the fluids to be analyzed were brought in small samples to the analyzing instrument, with the latter installed in more accessible areas with local shielding of the fluid sample lines. The mass spectrometer mentioned above would be particularly applicable in such areas.

To permit sampling without long

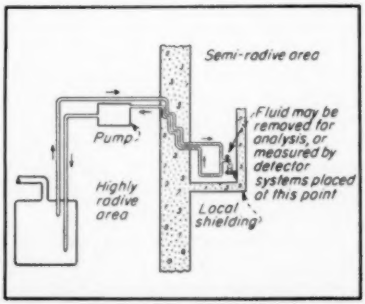
Semi-radive area
Fluid may be removed for analysis, or measured by detector systems placed at this point
Pump
Highly radive area
Local shielding

FIG. 7. Illustration of the advantages of automatic sampling techniques

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time delay, the fluid could be circulated rapidly through small-diameter pipe lines, completing a circuit from the process vessel to the instrument and back again (Fig. 7). With small line volume and rapid circulation rate, a time delay under 15 seconds is reasonable to expect, even when substantial separations are involved.

Aside from proper detector elements, the most important requirement for remote sampling purposes is a good pump which is leak-proof, suited for continuous operation over extended periods, and self-priming with high lift characteristics.

PLANT RADIATION MEASUREMENT

It was pointed out earlier that the presence of radiation in a plant presented both a hazard and a useful variable by which to monitor the process, since the concentration of radioactive materials is an important variable in these plants, and the measurement of emitted radiation constitutes the most direct measure of such concentration.

The radiation within process vessels often includes alpha and beta particles, together with intense gamma-ray activity. The radiation which passes through the vessel walls is largely gamma radiation, with some secondary emission. The spectral energy and intensity distribution of the radiation is usually complex, and extremely difficult to analyze. Obviously a good deal of advantage would result if the alpha particles could be identified and measured in the presence of intense gamma radiation, but such resolution is not easy to introduce in instruments that may be used in a plant, particularly since alpha particles become absorbed within even paper-thin walls.

The measurement of total radiation, or of gamma radiation would nevertheless prove quite useful if it could be done with suitable instruments. Such measurements might cover intensities ranging from normal background activities of roughly 0.02 milliroentgen per hour up to many roentgens per hour, although a single instrument would not have to cover this wide range. An instrument attached to an output pipe can easily monitor the process; it might also be attached to nonradioactive input lines to sound an alarm if the activity should creep into the nonradive areas. Similarly an instrument which is attachable to a vessel can help to determine total or specific solution activity, liquid volume or liquid level, and composition, either for purposes of automatic control or for alarm purposes.

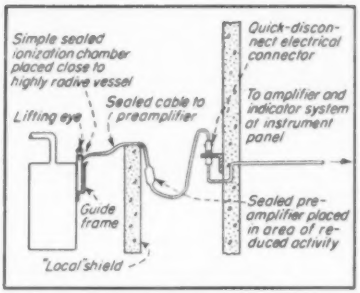
Simple sealed ionization chamber placed close to highly radive vessel
Lifting eye
Sealed cable to preamplifier
Quick-disconnect electrical connector
To amplifier and indicator system at instrument panel
Guide frame
Sealed pre-amplifier placed in area of reduced activity
"Local" shield

FIG. 8. Illustrating the use of a simple ionization chamber with sealed preamplifier and connector device

Despite the considerable value which radiation measurement can have for process control, there are few commercially available instruments which are suited for measurements in production plants, for the following reasons:

1. These instruments are complex and difficult to reduce to industrial design. Nevertheless they must in time be subjected to tests of performance under plant conditions, where line voltage surges, high humidity, changes in room temperature, corrosive fumes, vibration, abuse by unskilled workers, all combine to accentuate instrument failure.

As an example, there has been the tendency to make liberal use of miniature tubes and quick-disconnect plug-in

devices in these instruments, without sufficient appreciation of the fact that contact failures are much more frequent in such units than with large tubes or screw connections, especially since these instruments are subjected to industrial atmospheres for months and years. Appearance of the instrument cabinet has possibly received more than its share of attention as compared with the rating and life expectancy of component elements of the circuit.

2. Radiation-measuring detectors of the total-ionization, direct-current type are likely to be among the most useful for applications wherein the units must operate in inaccessible places over extended periods. To be useful, the ionization chamber should be small, to permit direct attachment to process vessels, pipes, or in strategic locations from which they can sight the vessel or area under observation. This frequently subjects the chamber and its materials of construction to high radiation intensities, against which the chamber must be made resistant (Fig. 8).

The chamber elements can be made reasonably insensitive to radiation, but the preamplifier elements are not likely to be so fortunate; consequently these should be given a measure of local shielding or separation from intense activity. The connecting cable between the chamber and the preamplifier should permit separation of perhaps 15 to 50 ft length. Often even this length is not sufficient to reach the instrument panels, and a much longer cable will have to be used to connect the preamplifier to the amplifier and meter at the instrument panel. A connector of the type described for resistance thermometer use would be exceedingly useful in this latter cable circuit.

The development of a small total-ionization chamber, sensitive to background and higher intensities, with a dependable amplifier system having the preamplifier separation and the cable connector described above, probably constitutes the most important instrument need for the measurement of radiation in a radiochemical production plant. The chamber might be of a gas-filled high-pressure type to reduce its volume, perhaps with some type of pressure-change indicator to show or give alarm when the gas pressure drops. It may be that research on solid- or liquid-dielectric chambers will reveal new principles that may result in the development of smaller chambers, perhaps also with greater or more selective sensitivity for the measurement of total or specific radiation.

There are other types of radiation measurement required in a plant. Measurement of activity of solution vapors, of stack and ventilating gases, and of wastes that are removed from the process, combine to pose serious problems. The measurement of air and vapor activity is at low levels that are very close to background intensities and are difficult to measure on a continuous basis. Because of the especially toxic nature of some of the radioactive elements, there arises the need for measurements that are specific to alpha or beta particles, sensitive to low levels.

CONCLUSION

The technical advances in the nuclear field have from the first been characterized by boldness and unorthodoxy. This boldness needs to be extended by process chemists, chemical engineers, plant designers, and industrial instrument men to develop instrument techniques that are forward-looking and suited to the unusual demands of radiochemical processes. The examples of the older industries offer useful lessons on methods of overcoming problems of process analysis; nevertheless this new industry poses problems of measurement which require the development of new detection techniques and new concepts of instrument dependability and performance. END

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Use of Radioactive Colloidal Metallic Gold in the Treatment of Malignancies*

For therapeutic administration, early studies with iron and manganese colloids pointed up certain limitations which led the investigators to seek a substitute. The colloids of pile-produced radiogold seem to offset some of these limitations and also provide a less costly treatment for malignant disease.

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THE PRIMARY AIM in the use of radioactive materials for treatment of malignant disease is to localize these materials in such a way that the maximum amount of ionizing radiation will be delivered to the tissue pathologically involved to the exclusion of nearby normal structures.

Very occasionally some element is concentrated by a physiological process in certain tissues. The outstanding example of this is the utilization of iodine by the thyroid. Physiologically, this has been properly exploited by a number of investigators in the diagnosis and treatment of hyperthyroidism and carcinoma of the thyroid. Unfortunately, most metallic elements and even organic materials do not show such a propensity.

There are two approaches to the use of metallic gold colloids. One of these is dependent upon the selectivity derived from the phagocytic activity of the lymphoid-macrophage system. The other depends for its selectivity entirely upon the manual dexterity of the operator and relies upon the inability of the body to dissolve metallic gold.

It is well known that the phagocytic system will pick up and deposit any foreign bodies which are put into the circulation. If the particulate matter is large enough, this will be strained out by the capillaries of the lung or brain. On the other hand if the particles are small, that is, considerably less than 1 micron in size, these particles will be taken up by the Kupfer cells of the liver, and phagocytic cells of the spleen, bone marrow, and lymph nodes (*3*, *6*).

Studies With Metallic Colloids

Earlier studies (*5*) had indicated that when colloidal ferric hydroxide was administered by vein this material was distributed in the reticul-endothelial system roughly in proportion to the amount of phagocytic activity. In other words, although the maximum concentration of the ferric hydroxide colloid was found in the spleen, the larger total amount was found in the liver inasmuch as this organ is much larger. Furthermore, the bone marrow was thought to take up considerable amount of the iron colloid.

Several years ago, the use of manganese dioxide colloids (*3*) was described

* This project is supported by the Division of Biology and Medicine, U. S. Atomic Energy Commission.

in the treatment of the lymphoid-macrophage system in which the rationale was based on the ability of these cells to phagocytose these extremely small particles. Actually, when the manganese dioxide colloids were employed and autopsy specimens studied, it was found that the spleen did not participate in the phagocytic reaction to the extent expected (*10*). No explanation has been found for this phenomenon.

Also, it might be mentioned that manganese tended to accumulate in the pancreas even though that organ has practically no phagocytic activity. This was probably due to the fact that the manganese was liberated in an ionic form following its deposition in the reticulo-endothelial system and was carried to the pancreas either for secretion, although it is known that this element is excreted largely through the biliary tract, or because the ionic manganese engaged in substitution with some prosthetic group of an enzyme in the pancreas.

When the chain-reacting uranium pile made other isotopes available, it became mandatory that another isotope be substituted for manganese. Two features made manganese unsuitable for therapeutic administration. Manganese is produced by a $(d,2n)$ reaction in the cyclotron, a relatively inefficient and costly process, which made the use of the material on a wide scale prohibitive. The experimental therapy of approximately 70 patients in one year necessitated the expenditure of roughly $10,000 in cyclotron time for bombardment. This was a prime factor in discouraging the further use of manganese for therapy, but so too was the fact that every bombarded sample contained in addition to the 6.5-day Mn^{52} about 1% of radioactivity due to 310-day Mn^{54}. Since little is known about the rate of excretion of manganese from the body, this would preclude the use of this isotope on a repeated basis in humans inasmuch as one might actually be using a carcinogenic agent if the manganese were retained by any particular system.

Selection of Gold Isotope

It was decided to search Seaborg and Perlman's tables (*8*) in an attempt to find a (n,γ) reacting material to meet the criteria described elsewhere (*4*). A comprehensive survey of these tables disclosed that only a few elements met the criteria. These elements were: sodium^{24}, copper^{64}, arsenic^{76}, bromine^{82}, krypton^{79}, yttrium^{90}, silver^{111}, iodine^{130}, iodine^{131}, lanthanum^{140}, gold^{198}, gold^{199}, bismuth^{207}.

The isotope which best suited our purpose was found to be gold^{198}. This has been used over a period of three years in the treatment of diseases of the lymphoid-macrophage system. The gold has the following advantages: Its half-life of 2.7 days is nearly an ideal one from the standpoint of "titrating" the patient's response. Its spectrum of 0.97 Mev beta particle and 0.44 gamma ray is very suitable. The beta ray is sufficient for the therapeutic requirements and the gamma ray is useful from a standpoint of localizing the material which is deposited in the desired tissues by means of suitable directional apparatus (*11*). Very important is the fact that it is prepared from a 100% abundant stable gold isotope, Au^{197}, which can be obtained as 24-karat gold with practically no impurities. This minimizes the amount of radioactive concomitants which can be produced by pile bombardment.

Gold, furthermore, has a cross section to thermal neutrons which is several hundred times as favorable as that of most elements and this allows the economic production of the 198 isotope.

The biology of gold is relatively well known. This is due to the studies for treatment of tuberculosis and rheuma-

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toid arthritis (although it should be stated here that the gold was administered primarily as an ionizable salt and not in the form of insoluble metallic colloid as employed in these studies).

Chemistry of Gold Colloids

The chemistry of gold is quite unique and has been known for centuries. The simplicity with which the gold colloid can be made, in contrast to the colloids of the manganese and silver elements, *etc.*, is a distinguishing feature in the case of handling. Very uniform colloids of red color can be readily obtained within a relatively few minutes.* The reduction of the gold chloride to the metallic gold colloid follows the addition of an excess of cevitamic acid to an alkaline solution of the gold chloride (*9*, *10*). The red colloid dispersed at *p*H above 8.0 has a particle size roughly of 40 to 80 millimicra. Larger particle sizes may be made by dispersing the colloid under neutral or acid conditions in which case a blue colloid will be formed having an average particle size of roughly 120–150 millimicra. The usual colloid form, the red one, has approximately two trillion (2×10^{12}) particles per ml of solution. Therefore in the treatment of the average tumor, approximately 20 trillion point sources of radiation are employed. This is in contrast, in the case of infiltrated tumors, to the employment of a half dozen or so radium or radon sources in which the beta rays, which are among the most useful of the ionizing radiations involved, have been filtered out by platinum or gold, respectively. It might be mentioned here that approximately 50% of the beta particles from gold travel about 0.38 mm in tissue. Thus the ionization due to beta particles is confined to the structures infiltrated or immediately adjacent to the colloid.

Distribution in The Body

In contrast to the distribution of manganese (*10*), gold is distributed roughly in the reticulo-endothelial system as would be expected of any foreign material and resembles in its distribution that of the iron colloids (*5*). Its concentration in the spleen is much greater than that of manganese colloid. Thus, in the treatment of the leukemia and Hodgkin's disease, this isotope should have advantages over the use of the manganese dioxide colloid. However, it is too early to state categorically whether the clinical results will bear this out.

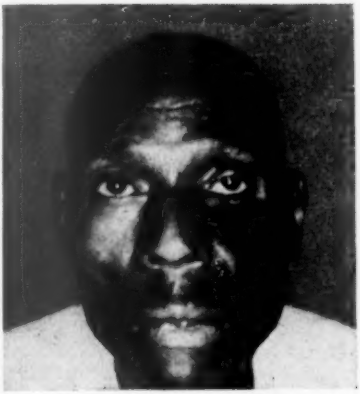
It was found in the attempted treatment of one case of leukemia that the lymphadenopathy in the cervical region did not respond satisfactorily, and a leukemia cutis existed wherein the skin lesions showed relatively little, if any, response to intravenous therapy. Direct infiltration of the lymph nodes that could be reached easily and the skin lesions was therefore attempted. Successful diminution in their size was attained.

Since gold is not moved about the body as are a number of other materials which are dissolved following phagocytosis, a number of attempts at direct infiltration of tumor tissue have been attempted in the course of the last three years. The detailed clinical accounts of therapeutic use of metallic colloidal radiogold in these various conditions will be published soon.

The chief limiting factor in the use of gold by direct infiltration of a tumor mass resides in the inability of certain friable tissues to contain the fluid which acts as a vehicle for the gold colloid. Many lesions, especially those found in the female cervix, are cauliflower-like in nature and therefore do not retain the solution involved. In the instances of

* Recently, the sterile, pyrogen-free colloid has been prepared for us by Dr. D. L. Tabern, Abbott Research Laboratories, from gold bombarded in the pile of the Argonne National Laboratory.

Lymphosarcoma treated by direct infiltration: One ml radioactive metallic Au^{198} sol representing 11 mc of activity injected into lower part of sacular lesion subsequently spreading spontaneously



Lesion 20 days later

metastatic hypernephroma and certain lesions of lymphosarcoma, the lesions were so vascular that the gold promptly gained access to the blood stream and hence appeared in the liver and spleen (*11*). Any well encapsulated or discrete mass, however, offers fertile ground for the use of this isotope in the delivering of ionizing radiation as a means of therapy.

Another advantage offered by radiogold is that, when given as infiltrative treatment for tumors, it may often be administered at a clinic visit to an ambulant patient in a single dose within a matter of a few minutes. This eliminates the necessity of hospitalizing the same type of patient for radium treatment or repeated visits for X-irradiation. Neither is a small hospital's supply of radium tied up for days for use in one or two patients.

In the case of direct infiltration of radiogold into tumors, one does not have to contend with the sensitivity of the skin to radiation. See photos on this page. Once under the skin, a tremendous amount of radiation can be delivered to subcutaneous and other tissues. It is altogether possible that many tumors formerly considered radioresistant (that is, tumors which could not be treated because of the lack of ability of the outer epithelial tissue to take the necessary radiation) can in the future be treated adequately with radiation from the inside working outwardly. The inverse square law operates in favor of the therapist rather than against him in using this material.

The chief problem with gold as an infiltrative agent in tumor therapy seems to be lack of knowledge of the tolerance of various types of tissue to beta-ray emanations. The tables and formulas devised by Marinelli, Quimby, and Hine (*7*) are useful in this respect, but one still must face the difficulty of determining the volume of tissue to be treated. In the case of a relatively simple spherical type of tumor mass, this may be fairly readily ascertained by measurement and calculation. In such instances, the dosage is expressed by $D_\beta = 76C^*$ equivalent roentgens. However, in elderly patients for example, breast tumors, accompanied by a

* Where C is concentration of radioactivity in microcuries/gram or millicuries/kilogram.

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considerable amount of ptosis, do not allow for simple calculations on the basis of symmetrical organs.

Also, with many other tumors, such as cervical lesions in which the tumor mass itself is not visible except on the surface, one can only by palpation get a rough estimate of the mass of tissue to be injected. Treatment of prostatic tumors by injection through a cystoscope has produced the same problem. The estimate of equivalent roentgens may easily be off by a factor of one third to one half in either direction; therefore the dosage may be in error by a considerable amount.

We might cite as an example a case of scirrhous carcinoma of the breast. The usual formula for equivalent roentgens was applied. It was decided to deliver 6,000 er initially to the mass in question. This relatively hemispherical breast was 13 cm in diameter and 7.3 cm in depth. There was an approximately pyramidal crater of excoriation, in which the altitude of the pyramid was 4.4 cm and its base 4.5 cm on each side. The estimated amounts of activity necessary to deliver 6,000 er to this tissue was 50 mc of Au^{198}. Actually, 61 mc* of gold were administered by direct infiltration. It was expected that surgery might be necessary in the event sloughing take place. Nothing of the sort resulted, however, although there was a very definite radiation reaction to the breast tissue. Six weeks later another injection of gold, 82 mc, was made; again this was expected to result perhaps in a massive amount of slough. It did not occur, and the patient was followed for a period of another month. At this time it was found that there was a mass above the treated breast which measured approximately 10 by 4 cm and rose about 1.5 cm. It seemed to be an extension of the original tumor. Thus, in spite of the fact that over 17,000 er had been delivered to this breast, there still was a definite indication of metastatic involvement of the tissue immediately surrounding. This tissue was treated by infiltration with 68 mc of radioactive gold colloid one month following the second administration to the breast lesion proper. The secondary mass disappeared and left a black pigmented area due to the radiation. The breast itself was subsequently infiltrated with 180 mc of Au^{198} resulting in its obliteration.

Lymphoid-Macrophage Disease

In the relatively short period—four years—in which manganese and gold colloid have been employed in the treatment of lymphoid-macrophage disease, it is difficult to give clinical evaluation of the results of therapy. The manganese colloids were used for approximately one year and the gold colloid for the next three years. As pointed out previously, the distribution of these two colloids is somewhat different as regards the spleen, in particular (*10*).

No attempt shall be made at this time to give the detailed clinical results of the therapy, although they will be reported in the near future. It might be said here, however, that the best success by intravenous administration of these colloids was obtained in the cases of chronic lymphogenous or myelogenous leukemia, the lymphomas, and lymphosarcomas. Since the use of the gold colloid by direct infiltrative procedures in tumors has been carried out for only about two years, it is too early to show what can be done in this regard. Some preliminary studies have been put on record (*2*) which show that, in fibrosarcoma and squamous cell carcinoma, desirable results can be effected. More recently several good remissions in lymphosarcoma have been achieved and will also be reported.

* The Lauritsen electroscope used in this laboratory for measurement of the gold millicurie was calibrated by Dr. W. C. Peacock at the Oak Ridge National Laboratory.

It is generally accepted that regardless of the form of ionizing radiation delivered to a tissue, the effect is the same for a given amount of ionization produced. This is true whether alpha or beta particles or gamma rays are used or whether high-voltage X-ray is delivered to the tissue in question. Therefore, the problem is in determining not only the amount of material to be used but also the amount of tissue to be irradiated. This is not a new problem inasmuch as the therapeutic use of radium and radon have always involved the same considerations.

It will be well to point out at this stage that radium, in full cognizance of the valuable use to which it has been put in the last thirty years, is a highly unsuitable isotope for therapeutic use. The only excuse for continued use would be based on the mass of accumulated empirical knowledge which has been developed regarding the dosage tolerances for this isotope. In using radium, one must filter out the alpha and beta rays, which are the most effective and useful of our ionizing radiations from this isotope, in order to avoid local necrosis about the site of implantation of the needles and seeds. Therefore, by using radium needles, one is employ-

Directional Geiger-Müller counter: Lead shield contains two gamma-ray tubes with preamplifiers. One, completely surrounded by lead, detects only background. The other detects background as well as radiation entering an aperture. Impulses from both tubes are fed into counting-rate meters and subtracted by a vacuum-tube voltmeter circuit. Removable apertures of various sizes are shown at right of chassis.

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ing a cross fire of gamma radiation with highly undesirable resultant damage to neighboring structures.

The use of radon seeds presents a similar critical objection in that this gas, an emanation from radium, is used in gold capsules implanted in the tumor mass with the idea of screening out the beta emanation and delivering only the gamma radiation to the tissue. Localized infiltration of a gamma-ray emitter is something which would be far inferior to a beta-ray emitter if there were choice involved. In fact, it should be noted that if radium or its daughter product, radon, had been discovered within the past 10 or 15 years, during which time over 800 other isotopes were discovered, neither would probably ever have been used in the treatment of a single tumor.

It may be argued that, with the gamma emission from radium, the regional lymph nodes are given desirable radiation, which would not be the case if a beta emitter were used. However, since dosages are calculated usually for the immediate tumor area, it would seem likely that the indirect-square law would hardly allow for adequate radiation from a gamma emitter which had been implanted for a calculated amount of localized radiation to the tumor itself. It is certainly true that a beta emitter of equivalent roentgen dosage would be very ineffective in furnishing any radiation to nearby areas which might represent lymphatic drainage.

In the earlier work with radioresistant tumors, such as scirrhous carcinoma, the calculated cancerocidal dosages usually used in more radiosensitive tumors were insufficient when based upon the beta dosage. As already pointed out, it was found that, when the skin erythema dose was not a contending factor, much larger dosages of beta radiation could be delivered to the tumor tissue without slough or undue necrosis of the nearby healthy tissue. In fact, in practice, it has become more and more apparent that in some of these radioresistant tumors one must use from five to ten times the calculated dosage to effect a remission.

About 10% of the ionization caused by an isotope of gold can be expected to be delivered from the one which emits 0.41-Mev gamma rays. Thus, as we approach dosages of beta radiation of the order of ten times the calculated amount, we are rapidly approaching the stage where the radiation from the gamma rays are of tumoricidal values. In such instances, the argument of lack of regional lymphatic radiation is negated. It should be kept in mind, however, that ideally we shall not likely encounter proper regional radiation until it has been found that the material being used as our beta radiation source has a tendency to be drained by the same lymphatic or circulatory apparatus as is the tumor tissue that is causing metastases. Such a goal is not improbable but is not in sight at the present writing.

For the intravenous treatment of Hodgkin's disease, leukemia, *etc.*, the volume of solution employed does not matter. Also, in the direct infiltration of large discrete tumors, especially those which are encapsulated, one need not be concerned about the matter of the tissue holding fluid.

Related Problems

In the treatment of cervical tumors, in particular, or in any tumors in which a small area is involved, it is sometimes a problem to get enough radiation into a given amount of fluid to be injected. In other words, the specific activity of the agent is of importance. It is not impossible, but is not easy and practicable at present, to make gold colloids in a concentration much exceeding 5 mg per cc, equivalent to present-day bombardments of about 20 mc per ml using the 198 isotope of gold.

When it is desirable to concentrate radiation from gold colloids beyond the 20 mc per ml (2–3 mg) cited earlier, one may make use of the carrier-free gold[199] which is obtained by the following reaction. Platinum[198] is irradiated with neutrons to give platinum[199] which decays by beta emanation with a half-life of 31 minutes to gold[199], which in turn decays with a half-life of 3.3 days to mercury[199] and emits beta particles at an energy of 1.01 Mev and gamma rays at an energy of 0.45 Mev. This material is carrier-free and can be produced in quantities such that the total amount of radioactivity can be induced in a minimum amount of gold metal. Thus there is no limit to the *concentration* of activities which can be attained by use of this reaction when it is impossible to make use of gold[198].

In this more highly specific active gold[199], a therapeutic agent for special selected cases can be developed. It can be made by bombarding platinum and removing the gold which has been converted by transmutation from the platinum metal. After the gold has been "milked" off the original target, it can be reinserted into the pile for further irradiation.

It is conceivable that such highly specific active radiations can be used in certain small but relatively "radiation insensitive" tumors where a terrific amount of bombardment must be delivered to small masses without destroying the superficial tissues. It should be noted, however, that the thermal neutron cross section of Pt^{198} is considerably lower than that of Au^{198} and, therefore, this reaction is much less efficient.

A Look at the Future

The potential uses of gold[198] and gold[199] are innumerable. Aside from the obvious applications which they have had to date, which were involved chiefly in finding what the individual tissue tolerances of easily accessible tissues were to radiation, it is necessary that a considerable amount of fundamental work be carried out to determine what the tolerances of such tissues as intestinal mucosa and muscularis and corresponding tissues for the stomach might be. In this way, it will eventually become possible to augment the surgical removal of tumors by the direct infiltration of the inoperable types of tumors or tumor extensions with radioactive gold colloids. Metastatic lesions can be infiltrated with at least the palliative effects which could be expected from the direct infiltration of X-ray or its equivalent under conditions which are not immediately practicable with X-rays at the operating site.

In no sense can it be felt that radioactive gold or any other isotope is a solution to the problem of therapy of tumors. In effect, one is treating the individual and not the disease. The etiology of the disease is of prime research importance.

In the use of all radioactive isotopes, the therapists should concentrate on malignant disease. There is seldom occasion for the administration of these agents in benign tumors or other benign diseases inasmuch as the possibility always exists of inducing carcinogenesis. This should be kept in mind even with the short-lived isotopes.

Artificially induced radioisotope therapy is at best only about 15 years of age. Most of the effort in the use of these materials has been directed toward the use of cyclotron-produced agents such as iodine, phosphorus, and sodium. Discouraging results with the use of these agents should not be construed as meaning that a hopeless attitude be taken toward the use of later and more efficiently produced pile products. In fact, it is necessary that we direct our activities toward the utilization of pile products since the economic factor is of essential impor-

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tance. In all likelihood only those isotopes which can be made by the chain-reacting uranium pile will have a large part in control of cancer in the future, the cyclotron furnishing an adjunct source of materials for specialized cases.

Radiation therapy of tumors has been largely developed on an empirical basis. More empiricism will be involved in the development of the use of the various isotopes suitable for therapy, but this does not mean that such use will be predicated on such untenable grounds as the use of radium and radon. It must be admitted that these last two isotopes, mother and daughter, have proved very useful in the treatment of a large number of human tumors in the past. It may be some time before enough is known about the tissue reactions from such isotopes as gold^{198} that full use of these very valuable tools will be made in the treatment of malignant disease.

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AT PRESENT, ALTHOUGH GOVERNMENT departments are making efforts to review and publish where possible some of the confidential reports which accumulated during the war, it is probably true that confidential reports are accumulating faster than they are being declassified. Every organization in Government or industry has an obligation to review its confidential reports periodically to see which can be made available to the general pool of scientific and technical knowledge. While this obligation is not always difficult to carry out, it is probable that with the existing arrangements for publication it would only mean an increase in the volume of nonconfidential unpublished reports, much of which occurs because of the lack of labor or incentive to prepare the reports for printing.

—D. J. Urquhart,
"The Royal Society Scientific Information Conference Report," p. 526
(The Royal Society, London, 1948)

NOMOGRAPH FOR MATERIALS IRRADIATION

This time-saving chart provides a means for determining the amount of material or irradiation time required to produce a desired source radiation intensity with a given pile flux.

By JANET M. CISAR

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IN THE USE of nuclear reactors for producing various radiation sources, valuable hours are spent in correlating cross-section values, irradiation times, and half-lives. The nomograph presented here was designed to require a minimum expenditure of time in calculating:

1. How much of a certain material is necessary to produce a desired source radiation intensity when irradiated in a pile of given neutron flux.

2. How long an irradiation time is practical at a given flux, or what flux is necessary to produce the desired source strength in a designated irradiation time, if only a given amount of material is permissible.

3. How intense a source radiation can be obtained from a certain amount of material when irradiated for a period of time equal to its half-life in a pile operating at a certain neutron flux. Quick comparison checks are thus possible to determine which of various materials is most applicable to the situation at hand.

4. How large a neutron absorption cross section is necessary with constant pile flux and source radiation intensity. This too provides a means for comparison of materials.

In constructing the nomograph, range limitations were taken as large as was practical, but, as in the case of half-lives extending over 10^4 years, they could not include all possibilities in use and retain sufficient accuracy. Irradiation time was taken from six minutes to about seven months (0.1–5,000 hours), which includes the usual workable range. Similarly, the pile neutron flux scale was constructed to bracket the useful range. Any of the scales may be extended as necessary by the user.

Several radiation values were computed for the equation given and were then checked against the nomograph values. The maximum error obtained with the original chart was approximately 2%. This error was caused by the thickness of nomograph lines; it is decidedly within that of values used for cross sections and neutron flux.

Derivation of Equation

The nomograph was constructed from the equation for source radiation intensity R, in curies per mole of activated material, which may be expressed as:

$$R = K\phi\sigma(1 - e^{-\lambda t})$$

where $K = (6.023 \times 10^{23})/(3.7 \times 10^{10})$ curies-sec/disintegrations/mole; ϕ = pile flux in neutrons/cm^2/sec; σ = thermal neutron absorption cross section in barns; λ = decay constant = $0.693/t_{\frac{1}{2}}$ in sec^{-1}; and t = irradiation time in sec.

This equation was derived in the following manner from the basic equation for the net number of radioactive atoms, dn, formed in time, dt:

$$\frac{dn}{dt} = [n_0 - (n + m)]\phi\sigma - n\lambda$$

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Nomograph for Materials Irradiation
Time Irradiated – Hours
Half - Life – Years
Half - Life – Hours
Thermal Neutron Absorption Cross Section - Barns
Flux in Pile - Neutrons/cm²/sec
Source Radiation Intensity
Megacuries
Curies
Microcuries
Flux = 10¹⁸ neutrons/cm²/sec
Flux = 10¹⁰ neutrons/cm²/sec
See text for explanation
0.0500
0.1000
0.9000
0.9900
0.9990
0.9999

where n_0 = number of atoms present at $t = 0$; n = net number of radioactive atoms; and m = number of atoms made radioactive and subsequently decayed. Integrating with respect to t:

$$n = \frac{\phi\sigma n_0}{\lambda - \phi\sigma}\left[1 - e^{-(\lambda+\phi\sigma)t}\right]e^{-\phi\sigma t}$$

Since $\phi \simeq 10^{11}$ and $\sigma \simeq 10^{-24}$, $\phi\sigma$ becomes insignificant in comparison with λ. Likewise, $e^{-\phi\sigma t}$ for most purposes will be sufficiently close to one to make the approximation:

$$n = \frac{n_0\phi\sigma}{\lambda}\left[1 - e^{-\lambda t}\right] \qquad \begin{matrix}\sigma\phi t \ll 1 \\ \sigma\phi \ll \lambda\end{matrix}$$

But rate of disintegration $= \lambda n$ sec^{-1}, and $R = \lambda n/(3.7 \times 10^{10})$ curies. Then:

$$R = \frac{\lambda n}{3.7 \times 10^{10}} = \frac{n_0\phi\sigma}{3.7 \times 10^{10}}\left[1 - e^{-\lambda t}\right] \text{ curies}$$

and, since the calculation is in terms of one mole of material, we finally obtain the working equation for R given previously.

Instructions for Use

Given: Half-life $t_{\frac{1}{2}}$ and thermal neutron absorption cross section σ of a material irradiated in a pile with neutron flux ϕ neutrons/cm^2/sec for a length of time t.

Find: Source radiation intensity of one gram molecular weight, R.

Method: *After each of the following steps, actual values are given in italics for a sample calculation with Y^{96}, using the following parameters: one mole* (96 *grams*) *of Y^{96} ($t_{\frac{1}{2}} = 62$ hours; $\sigma = 1.8$ barns), a pile flux $\phi = 7.2 \times 10^{12}$ neutrons/cm^2/sec, and 60 hours irradiation time. The calculation is shown on the nomograph by dotted lines with circled numbers corresponding to the steps here.*

1. Determine a value on the α scale as the point of intersection of a line drawn between t and $t_{\frac{1}{2}}$ on their respective scales. The result is $e^{-\lambda t}$. *For Y^{96} a line between $t = 60$ hours and $t_{\frac{1}{2}} = 62$ hours intersects the α scale at* 0.52.

2. The α value obtained in step one is converted to the β scale by means of connecting lines between the two scales. Slope of the line is determined by interpolating between lines shown, or the α-value can be subtracted from one to give β. *Drawing line 2 from $\alpha = 0.52$, we obtain $\beta = (1 - e^{-\lambda t}) = 0.48$.*

3. A line is drawn between the point on the β scale determined in step two and a point on the σ scale corresponding to the given value of σ. The intersection of this line with the R_A scale gives a value in curies or microcuries for the source radiation intensity at a pile flux of 10^{11} neutrons/cm^2/sec on the left-hand side of the scale, and 10^{12} neutrons/cm^2/sec on the right. *The line between $\beta = 0.48$ and $\sigma = 1.8$ barns intersects the R_A scale as shown. Neither scale corresponds to the pile flux given in this example, however, and we shall accordingly neglect numerical values and proceed to the next step.*

4. To determine an intensity using any pile flux between 10^{10} and 10^{15} neutrons/cm^2/sec, a line is drawn between the determined point on the R_A scale and the desired pile flux value on the ϕ scale. The resulting source intensity in megacuries, curies, or microcuries can then be read at the point where this line cuts the R_B scale. *A line between the intersection formed on the R_A scale in step three and the given value of 7.2×10^{12} neutrons/cm^2/sec on the ϕ scale intersects the R_B scale at 100 curies. Thus, the source radiation intensity from one mole of Y^{96} under the stated conditions is* 100 *curies.*

Other types of calculations, enumerated at the beginning of this article, can also be made. Since they involve a procedure similar to or the reverse of that given, they will not be detailed.

Note that this nomograph is constructed on the basis of one mole of material. To facilitate calculation of mass in grams of material needed, a second nomograph relating molecular

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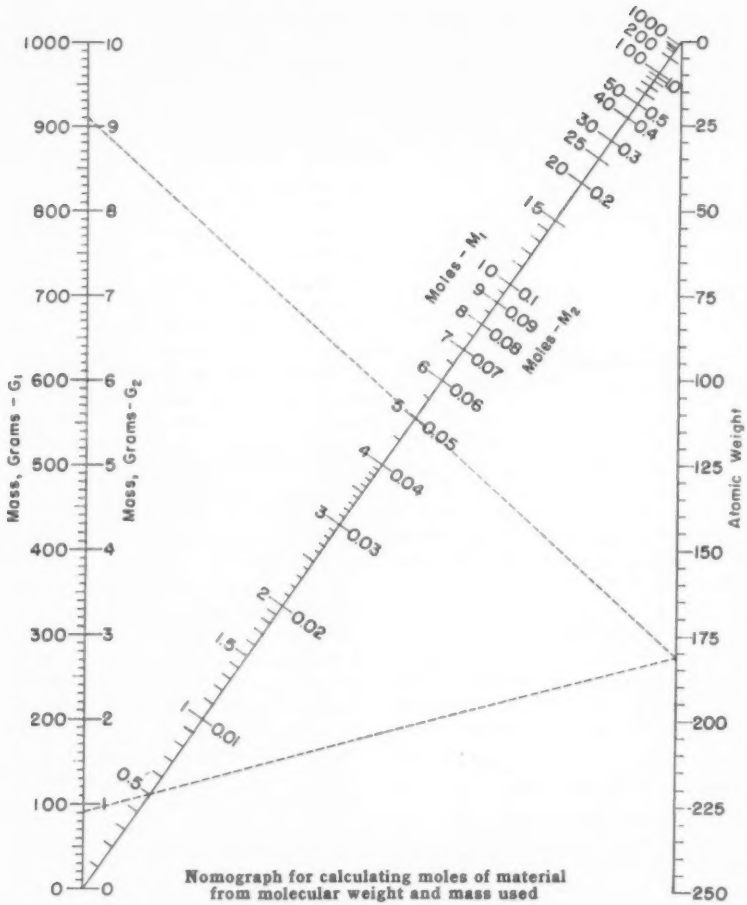

Nomograph for calculating moles of material from molecular weight and mass used

weight, mass, and number of moles has been included at the top of this page.

This second nomograph may be read in the conventional manner, its only ambiguity being that powers of ten are used. Two scales are calibrated for mass G and moles M; corresponding scales have like subscripts. The central part of the M scale is most accurate and usable. The dotted lines (drawn for Ta^{181}, 91 grams) illustrate how powers of ten can be adjusted to take advantage of this. Drawing from the 91 gram point on the G_1 scale to the molecular weight of 181 gives a value of 0.5 moles on the M_1 scale; using a value of $9.1 = 91 \times 10^{-1}$ on the G_2 scale gives $0.05 = 0.5 \times 10^{-1}$ mole on the M_2 scale.

* * *

Thanks are due to C. D. Susano and J. B. Trice for much of the basic information for these nomographs.

judgments about research programs since these are the most vague and long-range of the activities of the AEC. The new arrangement that has been set up whereby certain of the people in the Washington office have direct responsibility for research in certain of the national laboratories seems to be quite satisfactory. It is more appropriate for any of the laboratory directors to consult directly with a particular director of one of the research divisions in Washington about research programs than to have to go through the Oak Ridge Office or the New York Office of Operations.

Of course, it must remain true that budgeting and control of expenditures go through the local offices. It is, therefore, in one sense a parallel organization setup which might cause difficulties. These will be readily overcome by frequent conferences between the Washington research people, the directors of the laboratories and the men in the local offices who are primarily charged with research activities.

Future of the Laboratories

It should be frankly recognized that the whole scheme of national laboratories is a novel one, just as the whole AEC enterprise is a novel one in this country. There have, of course, been Government laboratories in the past but none on such a scale as these. There are certain dangers that can be spelled out even now. One is the danger of getting overlarge. One of the reasons previously cited for the existence of the national laboratories was our experience during the war with the effectiveness of large groups. The situation then was different; there was a sense of urgency and a sense of novelty which helped these groups to work harmoniously and effectively. Even so, there are those who argue that the best basic research is done by a few people working in isolation. Were it not for the very expensive equipment needed now for both basic and applied research, some would argue that the AEC might do better to put its money in university research rather than maintaining these big laboratories.

Need Dynamic Labs

The national laboratories must be alert to fight red tape, even red tape imposed on them by the AEC in Washington, to bring in new blood and to avoid the idea that a problem is necessarily best solved by spending several millon dollars on a new facility and asking the personnel officer to hire ten men who have Ph.D.'s.

It is also possible that the national laboratories may succeed too well. If their facilities and their salaries and their general atmosphere become as good as it is hoped they will, there may be a drift of the best men in science to them to such an extent that the university laboratories will be seriously weakened. At present the directors do not feel this way. They are very humanly more conscious of the good men that they want who prefer universities than they are of the good men that they get away from the universities. Right now the balance is probably somewhat in favor of the universities. It is not certain that it will continue so, but it would be very unfortunate for the AEC activities and for the country in the long run if the balance should shift too much in the other direction.

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Corrections for Beta-particle Self-absorption

It is often necessary in tracer work to take into account the self-absorption of beta rays in the samples. A simple method for the calculation of these corrections is described and its use is demonstrated in a series of measurements.

By A. H. W. ATEN, Jr.

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IN TRACER WORK, one often needs to know the specific activities of the preparations used. This means the activity per milligram of the radioactive element, and its quantity must be expressed in a unit of radioactivity. Usually a definite fraction of the total activity used in the experiment is taken as a unit; sometimes one of the samples is chosen arbitrarily as a unit.

In most determinations of the specific activity of a beta-radioactive material, it is not sufficient to measure and take into account only the activity of a sample and its weight; the relative efficiency of the counting arrangement must also be known. In the rare cases where different nuclides are compared, this part of the experiment constitutes a difficult problem indeed, and even when all samples contain the same tracer—the only situation to be treated in this paper—this question is not always easily answered. Therefore it sometimes escapes consideration, even when this is not strictly permissible.

As all radioactivity measurements are performed by comparing the influence of an unknown preparation and a standard source on a measuring apparatus (we shall assume the use of a Geiger counter throughout this article), it is natural to keep the geometry constant during the course of a series of readings. This means that the only item which can influence the efficiency of the measurement is the arrangement of the sample.

Here three influences must be considered: *backscattering*, *size*, and *self-absorption*. In some counters of very special design, these quantities are fixed by the shape of the counter. This is the case in the ordinary types of liquid counters, unless very concentrated solutions are used, but in ordinary tube or window counters all three factors depend on circumstances.

If only the thickness of the source need be taken into account, it is usual to calculate the activity which would have been measured if self-absorption did not exist. This figure we call "true" activity. Its value per unit weight is the "true specific activity."

Experimental Precautions

As a rule, it is easy to eliminate the influence of the backscattering by mounting all preparations in the same way. For solids, flat dishes stamped out of aluminum foil of about 0.1 mm thickness are satisfactory under almost any conditions. Where the metal is likely to be attacked, as in the case of silver halogenides, a layer of shellac offers excellent protection. For evaporating quantities of liquid, the same

type of dish may be shaped from platinum foil, although this material is more likely to develop cracks when pressed in a die. In this case it is advisable to have the standard on platinum foil too.

If it is necessary to compare samples on different supports, the thickness of the supports should preferably be not more than a small fraction of the range of the beta particles. If this is not feasible, thick supports should be used and corrections applied for the differences in backscattering as given by Burtt (Fig. 5 of reference *1*). The dependence of these corrections on the experimental geometry seems to be very slight.

The size of the surface of the sample rarely causes trouble. Solids as a rule can be kept from concentrating on special parts of the bottom of the dish, but difficulties may be encountered occasionally when small quantities of liquid are evaporated to prepare a "weightless" source. It is a general experience that dissolved material tends to be deposited near the circumference of the drop. However, as long as the source is appreciably smaller than the sensitive surface of the counter, inaccuracies are rarely serious, except with very weak beta rays such as those from C^{14} or S^{35}.

Contrary to the factors mentioned above, the self-absorption often cannot be made equal in different samples, and, in these cases, a correction must be calculated and applied.

There are, of course, circumstances, where corrections are unnecessary. In the ideal case, where all samples have "zero thickness"—meaning that no measurable absorption occurs in the preparation—no corrections are needed. Then the true specific activity is simply the ratio of the activity observed and the weight of the sample.

Another simple situation occurs when all sources are so thick that from the lowest layer of active material only a negligible number of beta particles reach the surface. This type of source is called "infinitely thick." Here the activity per cm is proportional to the radiation emitted from the surface per cm^2. This is strictly true only in cases where the composition of all samples is identical, but the influence of chemical differences is so small that it is usually not necessary to correct for them.

It is evident that the latter case represents the simplest technique of all, because, if all dishes have the same shape and if the quantity of material is sufficient, no weighings are required. Unfortunately, since only a small fraction of the beta rays originating in the source can be used for measurement under these circumstances, the method is restricted to experiments where a very large quantity of radioactive material is available, which in most investigations will not be the case. This method is very useful for analysis of potassium compounds by beta-ray measurement.

However, the presence of an appreciable weight of the inactive isotope in the sample to be measured is not the only reason for using thick sources. In most cases the active element is isolated by a precipitation and then the insoluble compound (for instance, $BaCO_3$, $BaSO_4$, $CaSO_4$, AgJ) or its decomposition product (for instance $Mg_2P_2O_7$) is normally used for the measurement. It is not at all easy to transfer a precipitate weighing a few milligrams from a crucible or from a paper filter to an aluminum dish without losing more than 1% or 2%. Therefore, it is a rule in many laboratories performing routine measurements that a sufficient amount of the inactive isotope is added before precipitation to obtain an active sample weighing between about 10 and 100 mg.

If the weights of all samples differ by less than about 5%, as always occurs when a large excess of the inactive isotope is added, comparisons can be made without applying corrections for thick-

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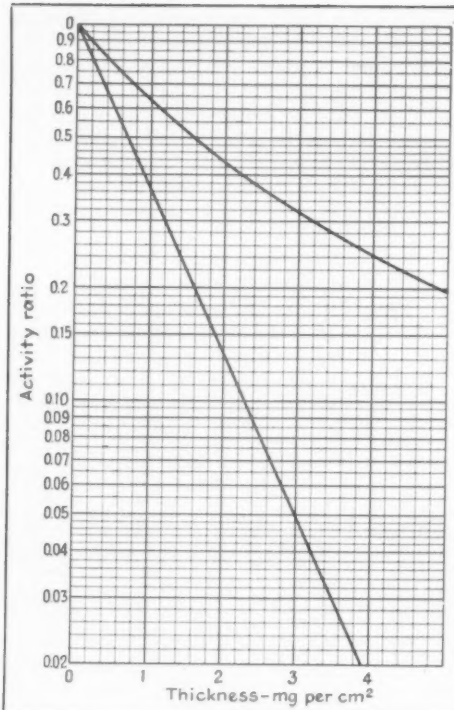

PROCEDURE

1. On ordinate, find value indicating ratio of observed activities with and without aluminum foil.
2. Find corresponding point on abscissa using lower graph.
3. Multiply this value by ratio of thickness of sample to that of aluminum (both expressed in mg/cm²). Find this value on abscissa.

If value obtained in step 3 is < 5:

Use upper graph and find corresponding point on ordinate. This is ratio of observed to true activity.

If value obtained in step 3 is > 5:

Ratio of observed to true activity is equal to thickness of aluminum divided by product of thickness of sample and value obtained in step **2.**

or:

Measured activity is equal to true activity of a layer with thickness equal to ratio of thickness of aluminum to the value obtained in step **2.**

FIG. 1. Correction for self-absorption

ness. Whenever samples are not very thin or infinitely thick, it is important that the material be spread out in as even a layer as possible. It should be realized, though, that even if this condition is not fulfilled, measurement is not impossible because the deviations caused by the thicker and thinner parts of the source cancel to a large degree.

As an example, we may point out by using Fig. 1 that if a layer of material is measured in which the apparent specific activity is equal to one-half the true specific activity and if now the same material is redistributed over the surface, reducing the thickness of one half by 50% and increasing the thickness of the other half by the same amount, the change in the measured activity does not exceed 7%.

The unevenness permissible in the surface depends on the absorption of the β-particles. In the case of radiophosphorus it is easy to make the sample sufficiently flat with a spatula. The same treatment is usually sufficient also with I^{131} and sometimes even Ca^{45}. With C^{14} and S^{35}, figures obtained with sources prepared in this way can be at best only a rough approximation. Here the most satisfactory technique is sedimentation of a suspension in alcohol (*2*).

Frequently, another simple way to obtain an even layer of a precipitate is

filtration on some kind of Büchner funnel. One may use either a flat cup with a perforated bottom, made of plastic or pressed metal foil (preferably platinum, the stiffness of which is very desirable for this purpose), which is put under the counter as such, or a normal type of Büchner funnel and lift the paper filter out afterwards. In this case the paper disk is transferred to an aluminum dish, the funnel scraped out and the rest of the precipitate dropped on top of the filter paper.

When a solid substance is sticky, it may be difficult to obtain an even layer by mechanical spreading. Here sedimentation or filtration are to be preferred; however, these treatments may take too much time if a great many measurements are involved. The simplest remedy is to change the routine and obtain a larger quantity of material. If this cannot be done, it is sometimes possible to distribute the lumps over the bottom of the dishes in a reproducible fashion, providing all samples have undergone the same treatment. In this way a large number of samples of calcium sulfate amounting to less than 10 mg/cm² have been measured in the author's department with duplicates agreeing within 20%.

Correction for Self-absorption

The derivation of the formula for self-absorption is simple. The absorption of beta rays in a substance like aluminum is approximately exponential and ξ is nearly independent of the composition of the absorbing material.

$$A_a = A_m e^{-X_a/\xi}$$

This formula is not exact, as is shown for Ca^{45} in Fig. 2. However, a more accurate representation cannot be given because of mathematical difficulties, because the shape of the curve is not quite the same for different nuclides, and because it depends on the geometry of the measurement and on the composition of the material supporting the sample.*

If we consider an infinitesimal layer with a true activity at a distance x below the surface, ($dA_t = \alpha\Omega dx$), we find:

$$dA_m = e^{-x/\xi} dA_t = \alpha\Omega e^{-x/\xi} dx$$

$$A_m = \int_0^X \alpha\Omega e^{-x/\xi} dx = \alpha\Omega\xi(1 - e^{-X/\xi})$$

$$A_t = \alpha\Omega X$$

$$\frac{A_m}{A_t} = \frac{1 - e^{-X/\xi}}{X/\xi} \qquad (1)$$

Most textbooks recommend the empirical determination of a graph relating A_m/A_t to X. This is satisfactory in cases where all measurements are made with the same counter and the same experimental setup. If, on the other

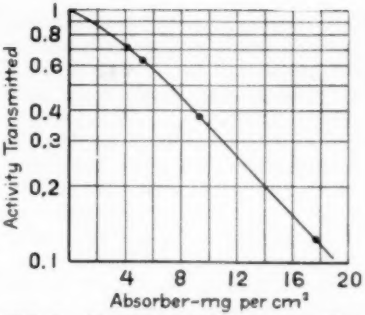

FIG. 2. Absorption of beta rays from Ca^{45}

Symbols for Self-absorption Formula

- A_m = Measured activity of sample
- A_a = Measured activity of sample through inactive absorber
- A_t = True activity of sample
- α = True activity of sample per mg
- Ω = Surface of sample
- X_a = Thickness of absorber in mg/cm²
- X = Thickness of sample in mg/cm²
- ξ = Absorption coefficient in mg/cm²

* The relation between backscattering and self-absorption is very complicated. It has been treated in several unpublished reports by N. Feather.

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hand, one is obliged to use a number of different arrangements, this method is not practical. Nor is it attractive if only a few determinations are made with one isotope.

For these reasons, it seemed desirable in the author's work to use the theoretical formula. As the calculations were tedious, a graph was constructed from which activity factor A_m/A_t could be easily read. It is reproduced in Fig. 1.

The application requires that after a sample has been measured the determination is repeated while the sample is covered with a layer of aluminum foil, mica, or some such material. Preferably this should cause a reduction of the intensity by something like a factor of 2. If a series of measurements is performed, it is unnecessary to measure the absorption of the radiation of all samples. One or two determinations are sufficient, for which it is important to use some of the thickest preparations.

The use of the graph is self-evident.

One starts with the lower curve (straight line) to find the value of A_a/A_m for the aluminum foil on the vertical axis. The corresponding value of X_a/ξ is read and multiplied by X/X_a. This value is taken on the abcissa and, by means of the upper curve, the corresponding value for A_m/A_t is read. This activity factor holds for the actual measurement, and the corrected activity of the sample is obtained by dividing the observed activity by this figure.

If the sample is very thick—more than 5 mg/cm²—the upper curve in Fig. 1 cannot be used. In this case, the intensity of the beta rays is equal to what it would have been if a layer of thickness ξ were present in which no self-absorption occurred.

$$\left.\begin{aligned} A_m &= \alpha\Omega\xi \\ A_m/A_t &= \xi/X \end{aligned}\right\} \text{infinitely thick layer}$$

This is, of course, the limiting value for $X = \infty$ of Eq. 1. From A_a/A_m, one obtains X_a/ξ by using the lower line; ξ is found by division of X_a by this ratio. This formula has been the basis for the study of weak radiations, as in the determination of the half-life of K^{40} by Brewer and Bramley (*7*).

TABLE 1

Values of ξ for C^{14} from Results Obtained by Different Authors

Authors		ξ (*mg/cm²*)
Yankwich, Norris, Huston	(*3*)	3.5
Reid, Weil, Dunning	(*4*)	3.3
Solomon, Gould, Anfinsen	(*5*)	3.4
Armstrong, Schubert	(*6*)	4.2

It seemed desirable to test the corrections obtained in this way by an actual example. For this purpose Ca^{45} was used, and the results* are given in the appendix.

If an absorption measurement with aluminum has not been made, correction factors (though not nearly as accurate and reliable) may be calculated from values of ξ published by other observers. To obtain a notion of the accuracy to be expected, values determined by different authors for C^{14} have been collected in Table 1. It seems that an inaccuracy of something like 25% should be expected. If no data are available at all, a very rough estimate of ξ can sometimes be obtained by taking ⅓ of the maximum range of the beta particles (*8*), which can be derived, if necessary, from the maximum energy (*9*). [This ratio holds for beta energies of the order of 1 Mev. For very soft beta-rays (*10*), ⅕ seems to be more accurate.]

* These data were obtained in connection with a series of measurements performed for C. B. Heyn (Leyden). The Ca^{45} had been allotted to him by the U. S. Atomic Energy Commission for physiological experiments.

Approximation for Moderate Thickness

Broda *et al.* (*11*) have suggested an approximate formula:

$$A_\infty/A_t = e^{-x/\Psi} \qquad (2)$$

In Fig. 2 this would represent a straight line, and the beginning of the curve in Fig. 1 is indeed approximately straight down to about the value 0.5. Both from the graph and by writing Eqs. 1 and 2 as a series, one finds $\Psi = 2\xi$. Broda and his co-workers suggest taking a straight line somewhat above the limiting slope of the upper curve, $\Psi = 2.2\xi$. This makes results less satisfactory for thin layers, but it slightly extends the range over which agreement is tolerably good.

There is another point to be mentioned. If very thin samples are used, results may be abnormally low, unless the source is very close to the window (*12*). This difference is due to the absence of the scattering action exerted by the sample itself at greater thickness. Deviations as high as about 30% may occur, but they are only noticeable in sources of less than 1 mg/cm² (*1, 12*). Therefore it is not likely to cause any trouble when only solids are measured, but inaccuracies may well result when solids are compared with aliquots of the total dose, obtained by evaporation of a fraction of the solution administered.

APPENDIX

Table 2 gives the results of activity measurements on a series of sources prepared from a single batch of calcium sulfate containing Ca^{45}. Each of the observations was corrected for self-absorption by means of an absorption measurement, performed on the sample itself.

It is seen from Fig. 2 that the absorption of beta rays is only approximately exponential. It is evident that, for the thinner samples, having correction factors greater than about 0.7, the exact value of the absorption is not very important. An inaccuracy of 20% in the absorption coefficient would cause a mistake of only 6% at the utmost. At lower values, the influence of the absorp-

TABLE 2

Correction for Self-absorption of Samples Containing Ca^{45}

Figure 1 is used. All activities are expressed in terms of the uncorrected activity of sample B as unity. The absorbing material was mica. Surface of all samples = 2.80 cm². All weights in milligrams.

Sample	*Weight of sample*	*Weight of sample per cm²*	*Measured activity of sample*	*Fraction of activity left after filtering through 9.3 mg/cm²*	*Activity factor*	*Weight of layer with true activity equal to measured activity of sample*	*True activity*	*True specific activity*
A	7.6	2.72	0.709	0.395	0.87	....	0.80	0.107
B	12.5	4.46	1	0.384	0.80	....	1.25	0.100
C	14.4	5.15	1.14	0.379	0.77	....	1.48	0.103
D	20.0	7.15	1.55	0.362	0.70	....	2.22	0.111
E	31.0	11.09	1.88	0.361	0.58	....	3.24	0.104
F	92.5	33.0	2.42	0.342	0.255	....	9.50	0.103
G	131.9	47.0	2.50	0.345	.....	24.6	....	0.102

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tion measurement is much more important, and, for an infinitely thick layer, an inaccuracy of 10% in the determination would cause an equal discrepancy in the correction for specific activity.

Evidently it is desirable, as mentioned before, in cases where absorption measurements are not performed on all samples, to determine this quantity for the thickest sources of the series, if available activities do not make this impracticable.

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Report on:

Meeting of Radiological Society of North America

Written by DR. OTTO GLASSER, biophysicist at the Cleveland Clinic Foundation and chronicler of the life and papers of Roentgen, this account reveals the fast-growing interest of medical personnel in the use of radiation in connection with some recent developments in their field.

THE THIRTY-FIFTH ANNUAL MEETING of the Radiological Society of North America took place from December 4 to 9 in Cleveland, Ohio. In the past thirty-four years, this society has steadily grown until the customary hotel facilities for annual meetings have become inadequate. This year shelter had to be found in the vast Cleveland Public Auditorium. Scientific and commercial exhibits were effectively displayed in the large main arena of the auditorium, while scientific sessions and refresher courses were held in the music hall, the little theater, and the numerous parlors in the building.

Some of the forty scientific exhibits were of special interest. V. M. Archer, M.D., University of Virginia, demonstrated his ingenious ray-protective coverall and decontamination suits made of lead fiber glass. The Naval Medical Research Institute had a most impressive display of some aspects of its radiological research program. Capt. C. F. Behrens and colleagues presented dosage measurements on 1,000 and 2,000-kilovolt X-ray beams and indicated the biological effects of these radiations produced on mice and pigs. Effects of gallium-72, a beta- and gamma-ray emitter with a half-life of 14.3 hours as well as of radioactive colloidal gold on pigs and rabbits was also shown.

K. E. Corrigan, Ph.D., Harper Hospital, Detroit, and Bernard Roswit, M.D., Veterans Hospital in the Bronx,

New York, had most instructive exhibits on the use of various radioisotopes in diagnosis and therapy. W. Howes, M.D., Brooklyn Cancer Institute, reported on the physical foundations of thorium X and its practical use for the treatment of epitheliomas, keratoses and radiation changes. Detailed studies of radiation quality and quantity emitted from a million-volt X-ray tube equipped with a beryllium window were offered by E. D. Trout of the General Electric X-ray Company.

More than forty commercial exhibitors presented all kinds of modern radiation equipment such as a 24-Mev betatron, new types of high-voltage X-ray tubes with special windows, various types of Geiger tubes and counting equipment, ionization chambers in measuring and survey types of instruments, and devices for the safe handling of radium and radioisotopes.

Therapy Information

The popular series of post-graduate instruction refresher courses of the Radiological Society were inaugurated on Sunday, December 4, with a two-hour panel discussion on therapy information with J. A. del Regato, M.D., Penrose Cancer Hospital, Colorado Springs, acting as moderator. This course was given in the large music hall and was attended by over one thousand people. Panel members were William Harris, M.D., Mount Sinai Hospital, New York; K. E. Corrigan, Ph.D., Detroit; Isadore Lampe, M.D., Univ. of Michigan; Manuel Garcia, M.D., Charity Hospital, New Orleans; and F. J. Buschke, M.D., Swedish Hospital, Seattle.

All questions had been submitted in advance and none were received from the floor. Practically all questions were of clinical nature, such as for example: What is the treatment of preference for a half-dollar-size hemangioma on the forehead of a six-month old child? What is the maximum permissible dose of X-rays for the treatment of plantar warts? Are all sarcomas radioresistant? What is an adequate tumor dose for the treatment of carcinoma of the cervix? The members of the panel were not always in agreement on their answers to all of these questions. Only one question was asked which pertained to isotopes. How do you treat chronic myologenous leukemia? The moderator directed this question to the only physicist on the panel, Dr. Corrigan, who stated that at Harper Hospital there is a team of experts who discuss the case and decide whether or not P^{32} should be given and in what dosage. The average dose is 6 millicuries if given by vein and about 8 millicuries if given by mouth. Good temporary recoveries lasting from 6 months to 2 years have been observed but permanent cures have not been achieved.

Another interesting discussion at this Therapy Information course was started by the question "What are the advantages of million-volt therapy over standard 200-kilovolt therapy? All members of the panel felt that million-volt therapy was a definite step forward. Dr. Lampe presented the most convincing and carefully analyzed arguments for that advance. The percentage depth dose for high voltage radiations is greater. Number and distribution of secondary electrons is greater and better. There is more forward scatter, and flatter isodose lines make for better dosage distribution. Consequently, the integral dose applied to the patient is small, which probably accounts for less radiation sickness of the treated patients. Absorption differential between bone and soft tissue is less, which accounts for smaller error in calculated depth dosages. All of these factors tend to increase the chances for the treatment of tumors which need just a slightly larger dose of radiation than

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could be applied with 200-kilovolt radiation. However, the over-all curability of malignant tumors is not greatly improved even with million-volt X-rays.

On December 5, B. V. A. Low-Beer, M.D., University Hospital, San Francisco, spoke on the evaluation of clinical usefulness of radioactive isotopes. Dr. Low-Beer enumerated the uses of radiophosphorus and radiosodium in both diagnosis and treatment. Of special interest was the demonstration of the treatment of superficial lesions by blotting paper soaked with a measured amount of Na_2HPO_4 solution containing a measured amount of P^{32}. Pieces of this paper can be cut to cover the lesion adequately. By means of this treatment method which was inaugurated by Dr. Low-Beer, over 90% of cases of skin carcinoma and hyperkeratosis remained controlled with no recurrence.

On December 6, H. M. Parker, Ph.D., Nucleonics Department, Hanford Works, Richland, Washington, gave a lucid talk on the Patterson-Parker system of dosimetry in radium therapy. Dr. Parker emphasized the fact that their system is a physical tool used for practical determination of gamma-ray dosages. Quick surveys can be accomplished by its use if the demands for accuracy are not too high. Dosages were calculated from point sources, linear sources, squares, rectangles, and rings. Radiation sources were combined in such a fashion that a uniform dose was obtained over a prescribed surface. Rules obtained on regular flat surface applicators were then extended to irregular flat surface applicators and to curved surfaces. Radiation emitted from cylinders was then calculated. Such applicators were first considered as consisting of a series of rings. Then they were taken as being "rolled-up" rectangles and the distribution of radiation from various sources within the cylinder wall was discussed. To explain the most desirable volume distribution of gamma rays in tissue, Dr. Parker chose several theoretical approaches but dwelt in greater detail on his own fluid distribution theory in spheres based upon the "rind and core" principle. Numerous practical examples of calculating gamma-ray dosages for various conditions were given. Lack of time prevented Dr. Parker from finishing his lecture much to the distress of his interested audience.

Course-Symposium on Dosimetry

Equally important and excellent courses on dosimetry were given by Edith H. Quimby, Sc.D., Columbia University, and K. E. Corrigan, Ph.D., Detroit.

Dr. Quimby lectured on dosimetry of internally administered radioactive substances. For both tracer and therapeutic applications of radioactive substances in the body, a knowledge of applied radiation dosages is of great importance. For X-ray and gamma rays, this dosage can be expressed in roentgens, but for beta radiation, the *equivalent roentgen* or the "rep" is introduced.*

For X-rays and also gamma-ray-emitting radioactive substances in sealed containers, dosage measurements can be easily made, and data for numerous experimental conditions have been collected in tables by various workers. For the application of radioisotopes in the body, satisfactory estimates of dosages can be made only if the radiation energies and the half-life of the isotope are known in addition to the uptake and secretion of the isotope in the body.

Dr. Quimby illustrated the methods of arriving at such estimates for beta-ray and gamma-ray emitters and derived relatively simple formulas for calculat-

* See L. D. Marinelli, Edith H. Quimby, G. J. Hine, NUCLEONICS 2, No. 4, 56; No. 5, 44 (1948).

ing therapeutic, diagnostic, or protective dosages for these different types of radiation emitters. The difference between the physical half-life of the isotope and the biological half-life of the isotope in the body was developed and the term *effective half-life* introduced.

With numerous practical examples, the use of these dosage formulas was demonstrated for: (1) determination of the minimum dose of a tracer isotope which will keep total body radiation of the patient below permissible levels; (2) determination of therapeutic doses; and (3) studies of proper protection of personnel.

Dr. Corrigan, in concluding this course-symposium on dosimetry, spoke on dosimetry in roentgen therapy. He divided his subject into two parts: dosimetry below and dosimetry above 500 kilovolts. Fundamental principles of ionization by roentgen rays and measurement of the ions formed with standard air and with thimble ionization chambers leading to the definition of the roentgen were discussed. This was followed by a study of scattering of X-rays in a medium and the numerous factors upon which the scattering depends. Tissue dosages were then introduced both in roentgens and in energy units.

For voltages above 500 kilovolts, all these factors become decidedly more complicated. The range of the secondary beta rays released by the impinging photons rises from 35 cm at 200 kilovolts to several meters at multi-million-volt X-rays. Standard ionization chambers are difficult to construct for such ranges and the roentgen is, therefore, not yet reliably defined for high voltages. Scattering is mostly forward, and energy distribution within the body is consequently entirely different from that for the 200-kilovolt radiation. Other factors such as pair formation and possible nuclear changes add to the difficulty of dosage determination at higher voltages, and the present status of measuring high-voltage radiation energies in any unit is still unsatisfactory.

Papers

Several papers on radiological problems presented before the society throughout the week of the meeting also merit mention.

C. B. Braestrup of New York City Hospitals warned against the indiscriminate use of the nasopharyngeal radium beta applicator which, for customary treatment use, may deliver a considerable overdose to the tissues adjacent to the applicator and also may contribute to an undesirable overdose to the operator.

W. E. Chamberlain, M.D., of Temple University, Philadelphia, presented a progress report on electronic amplification of X-ray fluoroscopic images, which was not too encouraging, largely because some of the work is carried on by big companies under the cloak of secrecy.

L. S. Taylor, Ph.D., of the Bureau of Standards, pinch-hitting for Dr. G. Failla of New York who was ill, suggested that, for the time being, the use of the roentgen for voltages below 300 kilovolts should be continued but that for higher-voltage X-rays, as well as for all other types of ionizing radiations, new units must be adopted.

R. R. Newell presented the last paper of the meeting in a most serious vein. Intense investigations, supplemented by questionnaires answered by many "presumed" experts, have revealed the discouraging fact that opinion on human "tolerance" for total body radiation varies from 25 to 1,000 roentgens. How dreadfully serious the lack of accurate data on this important subject might prove in the case of entering a contaminated area was forcefully presented by the speaker with a plea to collect more accurate data on the subject speedily. END

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Information for the Atomic Industry

The Editor critically reviews the atomic energy information program from the standpoint of NUCLEONICS' readership. Accordingly, certain proposals are made to introduce changes.

By NORMAN R. BEERS
Editor, NUCLEONICS

UNIVERSAL AGREEMENT is found with the statement that we need information on atomic energy and the developments in the program. Facts are the only sound basis for decisions on policies to guide the development and control of these primal forces.

Recent events such as Chairman Lilienthal's resignation, President Truman's announcement that an atomic explosion occurred in the U.S.S.R., and Senator Johnson's charges of a plot to disclose secrets to Britain and Canada have provided copy for the papers and, more important, suggest changes to come. Lilienthal has been quoted as saying the United States Government should end its monopoly of atomic energy; his views in detail should become available after he leaves the AEC, and they will be of tremendous importance to industry because of the esteem in which he is held, especially at those levels within the Commission where major shifts in personnel are unlikely.

Top policy decisions are important in any information program. But it would be folly to forget that facts are discovered and information actually disseminated at the working level. Instructions for these people are sadly in need of revision. The situation may improve after the January meeting of the AEC's Senior Responsible Reviewers for declassification, and the forthcoming February meetings, scheduled to be held in England, for review of the Declassification Guide.

Emphasis is placed on the U. S. Atomic Energy Commission and on its contractors throughout this discussion simply because the bulk of the information available comes from them. NUCLEONICS accepts (and encourages the submission of) papers from abroad, but a few minutes with the magazine shows how great our reliance on the AEC and its contractors is.

We Cannot Afford Complacency

The atomic physicist Goudsmit has written in a letter to *The New York Times*, "By all means, let us understand clearly and admit openly that the Russians constructed their bomb all by themselves, without any help from us or from captured Germans. *It is very wrong to underestimate one's adversaries* (emphasis supplied)." By experience in every way, Goudsmit, author of *Alsos*, is in a position to know.

The AEC's own Hafstad, Director, Division of Reactor Development has stated that the Canadian Chalk River reactor is of more advanced design than any reactor in operation in the United States. Canada has announced the availability of radioisotopes, some of which are not procurable from reactors in the United States.

Shields Warren, Director, Division of Biology and Medicine, U. S. AEC,

termed treatment for radiation sickness "way behind the times" last August in a press conference held on release of the Commission's Sixth Semiannual Report to the Congress of the United States. We assume without fear of contradiction that the program has not changed radically nor been greatly extended since.

We must also recognize that there are other alternatives to complacency than fear. The *New York Herald Tribune* editorialized following Secretary Johnson's speech of December 7, "The best climate in which to work for security is one shadowed by a sense of insecurity, a realization that the tireless and terrible ingenuity of man in devising ways of war threatens every placid assumption, and can only be met by equal vigilance and equal imagination." This, it seems to us, carries the matter much too far. The thinking man will recognize the basic *principle of uncertainty in life*;* he will also wear the knowledge lightly and see to it that there is no interference with his daily work.

Public Information

The growth of public information (and sometimes misinformation) in atomic energy is amazing. One who bothers to survey the content of a dozen or more newspapers immediately following announcement of some important event will find almost as many different opinions—to say nothing of headlines. Among these, the layman with little experience has to choose one as accurate.

The AEC has now started a series of monthly press conferences, the first of which in Washington resulted in some thirty pages of mimeographed proceedings. Chairman Lilienthal is reported to have opened the second held in Chicago with the statement, "There is no new news." Yet newspapers devoted considerable space to some aspects of the conference, for example, Hafstad's discussion of homogeneous reactors, a discussion that does not appear to have added anything to what has been printed in NUCLEONICS and elsewhere on the same subject. It would appear that less discrimination is exercised by writers and editors in atomic energy than in other fields that are equally newsworthy. The sports writer who filed a story on last week's race as if it occurred yesterday would find short shrift from his public; science writers should be as cautious.

The real danger arises when the mass of material available is so great that it cannot be (or is not) carefully screened for important items. One wonders whether important events or disclosures are not hidden, by design, among a mass of detail. Who reads the small type on his insurance policies? How many have found the time or the urge to read the full documentation of the investigation into the AEC? Whether virtual or real, the technique of verbosity endangers the very structure it is supposed to defend.

NUCLEONICS becomes particularly concerned when press releases of technical conferences are not followed by a discussion of what was said at the conference. Within the past few weeks, for example, conferences were held in England and in Canada on reactor safety and on permissible doses of radiation, respectively. It is quite feasible to believe that the former conference resulted in a discussion that ought to be held off the record because of national security. But, if so, is there any good reason why this cannot be stated, once the fact of the conference and its subject matter have been announced? The conference proceedings on radiation doses to be permitted in industry, on the other hand, cannot conceivably be delayed by national security considerations. If this latter subject has been classified, only admin-

*See NUCLEONICS' editorial, this issue, pages 2–3.

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istrative convenience can explain it—again once the fact of the conference and its subject matter have been widely published.

Most important for NUCLEONICS' readers are those press releases such as AEC No. 235 of December 13, 1949, entitled "Potential Industrial Uses Among Subjects of Atomic Energy Reports Issued in October." To make a good "story," the rewrite man will certainly delete the word potential, but in so doing he distorts the facts. The list of documents appended is so long and so clearly technical that it is probably not read by the press and it is certainly not published. A similar list "Atomic Energy for Industry" that apparently originated in the technical rather than public information service was screened and published in NUCLEONICS. The lists contains only a few documents which, if published, would excite industry, but editors would probably not find them exciting enough to request permission from author and/or AEC to publish.

International Affairs

Industry along with the rest of the people is interested in the possibility of international control of atomic energy. Books have been and are being written on this subject, and we will but mention certain boundary conditions that may be overlooked by nonscientists. Jack J. Bulloff of Champlain College, speaking before the American Chemical Society in September, 1949, for example, speaks of the main principles of the Baruch plan becoming inoperable whenever any non-fissile augmentation of nuclear energy is demonstrated. Of what value is Government ownership of all fissionable material, towards national security, if nuclear energy is released by fusion?

We have little doubt that the top planners of the Government are closely associated with the best atomic scientists in a consulting capacity. The arguments for and against the atomic bomb as an absolute weapon could become endless, as they have largely been shown futile; but in so far as they take energy from the business of scientific investigation into all aspects of nucleonics, these arguments and discussions are dangerous to our well being.

One of the most significant reports we have seen recently is from the Committee for Economic Development condemning "the present trend toward undue secrecy." After eighteen months' intensive study, the Committee gives specific recommendations for top-level administration in government respecting national security. More and more people are learning what should have been obvious from experience many years ago with The Great Wall of China. As phrased by an editorial in the *Detroit News*, NUCLEONICS contends that the best chance of keeping ahead of Russia (and/or any other country) may well lie with having an American atomic industry no more secret than the American steel or auto industries.

Secrecy and Classification

It is appropriate to recognize that secrecy is not unique to Government. The Employees' Handbook of one firm reads, for example, "*XYZ* is developing new products in a highly competitive field and is working on private development for outside commercial firms. These development programs frequently cover years of work. . . . The nature of these development programs must not be divulged to persons outside the Company who are not specifically authorized to receive such information." This seems a fair statement of policy, one to which honest exception would be hard to take.

The essential differences between Government and company secrecy are worth more attention than they can be given here. We may return to the

report of the Committee for Economic Development which asserts that classification of information is now being left to "clerks and secretaries." AEC instructions for processing classified matter clearly designate that only responsible persons shall have the right to "classify" matter, especially as SECRET and TOP SECRET. But, in practice, the recommendations of the writer of a report are usually followed and, in practice, the recommendation is usually to classify as "high" as possible; the law has teeth if restricted data are divulged, even unknowingly, and contractors who desire to maintain excellent relations with the Commission prefer to upgrade rather than downgrade documents and devices in their classification.

Once classified, the fat is in the fire. For the persons who may say that a document is SECRET, say, are not empowered to reverse the procedure at a later date and declare it declassified. Declassification is often a long and laborious process, requiring the reading of documents by many experts, who may recommend to appointed declassification officers, who in turn may refuse to declassify or refer the matter on to others for consideration. Documents have finally come to NUCLEONICS for publication as long as six months after being turned in for declassification by their authors. And these are not isolated cases.

Bulloff complained at the American Chemical Society meetings that, while the declassification and release of documents by the AEC is a great and noble task, the information is censored information, that it is not released in order of accomplishment, and that its valid scope is threatened by certain considerations not usually the subject of free discussion. This statement, no doubt, refers in part to the fact that the Declassification Guide, on which reasons for classification or declassification must ultimately be based, is itself classified.

It must also be borne in mind that declassification officers are faced with written instructions to the effect that matter will be declassified only where its immediate usefulness to the United States would outweigh its potential usefulness to an unfriendly nation. Furthermore, nothing is to be declassified unless there is a genuine requirement for the information in declassified form. Since industry generally is not *Q*-cleared for atomic-energy documents until after contracts have been discussed, there has been no significant pressure exerted for declassification.

Appointment by the AEC of the Kirkpatrick Committee to undertake a test program for making declassifiable information available for the use of American industry should help. But the first meeting of this Committee was held on September 1, 1949, and, so far as has been announced, no action has followed except to *Q*-clear members of the Committee, a necessary first step. Even so, there is some pessimism among industrialists. One responsible official told me he believed the AEC appointed Committees largely to save face and not to obtain action; he quoted the few results that have come from the long report of the Parker Committee which, in fact, suggested that the Commission declassify and publish more technological information of use to industry. And a top consultant of the AEC told me he was afraid the results would be disappointing, that very little publishable information would be obtained for much hard work.

Unclassified Areas

Certain areas of investigation have been declared unclassified by the Commission. Within these areas, scientists and engineers are free to publish their results without going through the classification-declassification routine. NUCLEONICS urges that these areas be broadened in the light of recent history,

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notably Russia's attainment of the bomb, and that the emphasis *all down the line* from Congress to the research worker and engineer be to obtain security by accomplishment rather than to risk loss through concealment.

"Unclassification" is especially important in those papers of one or more years' age written in many instances by authors no longer under the jurisdiction of the Commission. Several of these men have told me they would far rather see younger men now active in the particular subject write the papers over and have them certified unclassified by a board of experts (which is now possible at most installations), even though no credit might accrue the original author, than bother to check them and bring them up to date now. Such unclassified papers may be submitted directly to NUCLEONICS (or to other journals). They do not require clearance through Washington or through any AEC Declassification Officer. But this applies only in unclassified areas, which themselves need and will no doubt receive early clarification by the Commission.

AEC Technical Information

The Technical Information Program of the AEC has been well described in the Fifth Semiannual Report of the Commission. Its major task is to disseminate information to various AEC installations and to its contractors; this task is well done. The fact that highly classified documents are safely stored in safes more than they are used is no fault of the information service but of the fact of secrecy itself. Highly important plans and conclusions are often not known by those who need them in their work, sometimes because of the extra effort required in a busy day to obtain the SECRET file from the proper storage, and perhaps still more often because those who have the documents believe themselves the only ones qualified to know their contents.

The AEC also makes available many documents for sale. Some are obtainable from the Government Printing Office; "Handling Radioactive Wastes in the Atomic Energy Program" is a recent and useful example. Other documents may be obtained through the Technical Information Branch, Oak Ridge, Tennessee. Lists of documents are also published and obtainable from Oak Ridge. The precise status of the large majority is not clear. It will be recalled that a publication of the GPO is not protected by copyright; the documents from Oak Ridge are sometimes neither classified nor publications of the GPO, and the question whether they may be used freely has not been answered. Some deserve wider distribution than they get in their present form; others neither deserve it nor will get it.

How to Do Business with the AEC

The Superintendent of Documents, U. S. GPO, now sells for 10 cents an 18-page pamphlet entitled "U. S. AEC Contracting and Purchasing Offices and Types of Commodities Purchased." This contains lists of the supplies, materials and equipment being purchased by or for AEC and its contractors, the addresses of the purchasing offices and agents and instructions on how a business firm may be considered to receive invitations to bid.

The AEC pamphlet was published particularly for the assistance of the smaller business concerns of the United States. The point is emphasized that in order to obtain business from the AEC or its contractors it is not necessary to employ counsellors, advisers, or any agents or agencies. In accordance with statutory requirements, certain information is added with respect to methods of procurement and security.

From personal experience with one of the large AEC contractors, as former Leader of the Meteorology Group at Brookhaven National Laboratory, I am

happy to add these facts. First of all, the individual charged with responsibility for construction of a laboratory or other project, is given full opportunity to obtain the equipment he believes is essential to carry out his assigned duties. Irrespective of the named purchasing agent, who in fact makes the purchase for the contractor, the goods purchased must satisfy the user who receives them. And, secondly, the choice is in the great majority of cases made from the catalogues or advertising matter of firms which the ultimate user knows.

It may also be remarked here that a majority of those who initiate requests for supplies, materials and equipment being purchased by or for the AEC and its contractors are young men (the atomic industry is still a young man's industry) who rely on current literature to keep themselves informed of what new products are available.

The large contracts for development and construction are different. The smaller firms need not expect to receive multimillion-dollar contracts when large industrial and engineering firms compete, except in the not impossible event personnel of the smaller firm are considered better qualified. Especially in the field of the large contracts, a clarification of AEC policy would be welcomed by all industry. NUCLEONICS has invited such contributions from the Commission. Contributions have also been invited from a number of the large contractors.

In doing business with the AEC, and within the structure of the AEC and its contractors as well, words of wisdom came from an official of one big company in saying, "There are no longer any differences between us and our competitors as far as machines, methods or processes go. We all know the same things about how to make the product. A company's edge now lies only in more effective use of its people."

Conclusions

The information program for the atomic industry is vigorous and generally healthy. But it has grown rapidly and requires re-examination to provide the best possible assistance. The Commission has indicated it welcomes constructive criticism and the help of industry in solving its problems. This cooperation should be extended not merely on the rare occasion of immediate necessity, but routinely and with a fixed determination to see that recommendations are accepted or bettered. There is no excuse for not following through.

FARADAY expressed it very well (he always did) when he described the three necessary stages of useful research—the first to begin it, the second to end it, and the third to publish it.

—Sir Robert Robinson, P.R.S.
"The Royal Society Scientific Information Conference Report," p. 15 (The Royal Society, London, 1948)

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CROSS SECTIONS

Cosmic Ray Research Disproves Magnetic Sun Theory

Cosmic-ray research carried on 20 miles high over northern Canada has disproved the widely accepted theory that the sun acts like a powerful magnet.

This development has been announced by the National Geographic Society as the outcome of a late summer research program conducted above the shores of Hudson Bay under sponsorship of the society in collaboration with the Bartol Research Foundation of Swarthmore, Pa., and the Defense Research Board of Canada.

Disproven Theory

The research project was under the direction of Dr. Martin A. Pomerantz of Bartol Foundation, who used the Canadian defense outpost of Fort Churchill as his operating base.

The theory he set out to test was that the sun possesses a permanent magnetic field, having a strength at its surface roughly 100 times that existing at the earth's surface and thus able to prevent any primary cosmic rays of low energy from ever reaching our globe. According to the old hypothesis, this solar field would operate to keep the intensity of the radiations at a constant level north of a particular geomagnetic latitude.

Dr. Pomerantz reports, however, that his Churchill experiments recorded cosmic radiations of such small penetrating power that they could not have entered the earth's atmospheric domain had a permanent solar magnetic field been operative to the extent long assumed by many scientists.

On the contrary, Dr. Pomerantz said, the expedition found no evidence to indicate that any observable permanent field exists. Even if the assumed solar field had only one-twentieth of the strength previously ascribed to it, he explains, the weak rays recorded by the expedition would have been held back.

(The activity of sun spots is accompanied by magnetic phenomena of widely varying intensities, but the magnetic fields set up by these sporadic outbursts are quite distinct from the concept of a permanent solar magnetic field which was under investigation.)

At Atmosphere's Edge

The research was carried out at altitudes varying from 100,000 to 110,000 feet, the zone representing the outermost one percent of the earth's atmosphere. These observations can be made only at great heights because the relatively low-energy primary cosmic rays which must be detected undergo structural changes, and are absorbed before they penetrate very deeply into the earth's atmospheric envelope.

Free-balloon flights carried aloft a four-fold coincidence arrangement of Geiger counters for the work. Whenever a cosmic-ray particle passed through the four counters in a certain direction, a signal was produced and relayed to a mobile laboratory on the ground. Instruments also transmitted continuous information regarding atmospheric pressure and temperature inside the miniature gondolas carrying the scientific equipment.

Individual flights lasted from six to twelve hours. Although outside temperatures at the 20-mile altitudes averaged about 60° F below zero, a

special arrangement within the gondolas maintained the apparatus practically at room temperature.

Wide Voltage Variance

Previous experimental programs have established that only cosmic rays of great energy can penetrate into equatorial regions where the earth's magnetic field is the strongest, and has the effect of deflecting intruding radiations. The lowest energy of cosmic rays arriving vertically at the equator is of the order of 14 billion volts.

Co^{60} and Zn^{65} Gamma Rays

Values of the gamma radiations from Co^{60} and Zn^{65} have been accurately evaluated by E. H. Jensen, L. J. Laslett and W. W. Pratt.* The values determined for Co^{60}—1.16_9 and 1.33_1 Mev—are consistent with those found recently by other investigators. These values, when used in conjunction with previous data from a composite source in which both Co^{60} and Zn^{65} activities were present, gave a value of 1.11_8 Mev for the Zn^{65} gamma ray.

These energy determinations were obtained by measurement of photoelectric conversion lines by means of an iron-free magnetic lens spectrometer. The internal conversion line corresponding to the 2.62-Mev gamma ray of ThC″ and the F-line from ThB was used for comparison purposes.

Beta-ray Applicator

A beta-ray applicator, with radioactive strontium as the source, for use in eye treatments was described at the recent annual meeting of the American Roentgen Ray Society in Cincinnati. The Sr^{90} replaces radon which was previously used as the source. The latter was unsatisfactory because of its short half-life, accompanying gamma rays and the difficulty in determining the beta-ray dosage.

The radiostrontium is completely enclosed in a lucite capsule, which is in turn deposited in an aluminum applicator. This is used in direct contact in treatment of numerous serious eye ailments.

This work was reported by Hymer L. Friedell, Charles I. Thomas and Jack S. Krohmer.

Radioactive Tracers Used to Study Plating Process

A better understanding of the mechanism of electrodeposition in chromium plating has resulted from recent studies† by Fielding Ogburn and Abner Brenner of the National Bureau of Standards using radioactive tracer techniques. By tagging either the trivalent or the hexavalent chromium ion in a chromic acid plating bath with radioactive chromium-51, it was conclusively shown that metallic chromium is deposited out of the bath from the hexavalent state rather than from the trivalent state, as had previously been suggested. In addition to solving a long-standing problem in electrochemistry, the work of NBS has demonstrated the utility of tracer methods as a tool for research on industrial plating processes.

Chromium plating is widely used to provide a hard wear-resistant coating on machine parts and for decorative purposes on such products as automotive grillwork and bathroom fixtures. For commercial plating of this

* AEC unclassified document, AECU-559.
† Fielding Ogburn, Abner Brenner, *J. Electrochem. Soc.* **96**, 347 (1949).

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Placing a Geiger counter inside a tube upon which radioactive chromium-51 has been deposited. The counter and radioactive tube are kept within the radiation shield of lead bricks (right) while the amount of gamma radiation emitted by the deposit in a given time is recorded on the scaler (background) attached to the counter

kind, the chromic acid bath, first reported in 1856, is at present practically the only chromium plating solution in use. This bath is prepared by dissolving chromic acid anhydride (CrO_3) and a little sulfuric acid in water. Initially, all of the chromium in the solution is in the hexavalent state; but when the plating current is applied, an excess of some trivalent chromium is formed by reduction of the hexavalent chromium at the cathode. This has led to numerous investigations into the mechanism of the electrodeposition process to determine whether the chromium is deposited directly from the hexavalent state or through the trivalent form. Several supporting arguments have been advanced by advocates of each theory of chromium deposition, but until now neither hypothesis had been conclusively proved.

Five chromic acid plating baths were prepared, and a small quantity of radioactive trivalent chromium was added to two of the baths as chromic chloride ($CrCl_3$) while hexavalent chromium was added to the other three baths as radioactive chromic acid anhydride (CrO_3). Chromium deposited from the first two baths was inactive. On the other hand, deposits from the baths in which the hexavalent chromium was tagged were found to be radioactive, and their activities were close to those of deposits from a bath containing active hexavalent chromium and no trivalent chromium. It was thus evident that the metal is deposited from the hexavalent rather than the trivalent state.

The solution of radioactive chromic chloride was prepared from small pellets of chromium metal containing a minute quantity of chromium-51. The pellets were weighed and dissolved in hydrochloric acid. Excess acid was removed by evaporating to dryness, and water was added to the residue.

Radioactive hexavalent chromium was prepared by adding hydrogen peroxide and sodium hydroxide or ammonium hydroxide to a portion of the solution of active trivalent chromium and heating the mixture on a steam bath. When all the chromium had been oxidized to chromate, the solution was evaporated to dryness to remove excess ammonium hydroxide and hydrogen peroxide. The residue was then dissolved in water.

The deposit from the plating bath was made on brass tubes 1 in. in diameter and 10 in. long. Each tube was supported vertically inside a cylindrical porous cell within a liter beaker. The anode was a cylindrical sheet of lead that fitted the inside wall of the beaker. The porous cell served to prevent anodic oxidation of trivalent chromium during the electrolysis. Chromium was deposited at a current density of about 30 amp per sq cm for intervals of 5 to 7 minutes, and the weight of the deposit was determined by weighing the cathode before and after plating.

Chromium-51 is a soft gamma-ray emitter with a half-life of about 26 days. Its radioactivity in the solutions and

the deposits was measured by means of a thin-walled, glass gamma-ray counter connected to a scaler. At the end of the plating process the Geiger counter was placed within the brass-cylinder cathode and the activity of the deposit was counted for 30 minutes. The tube was then rotated through 180°, and counting was continued for another 30 minutes. A background count was also made with an unplated brass tube for the same period of one hour and was subtracted from the count for the plated tube to give the correct value.

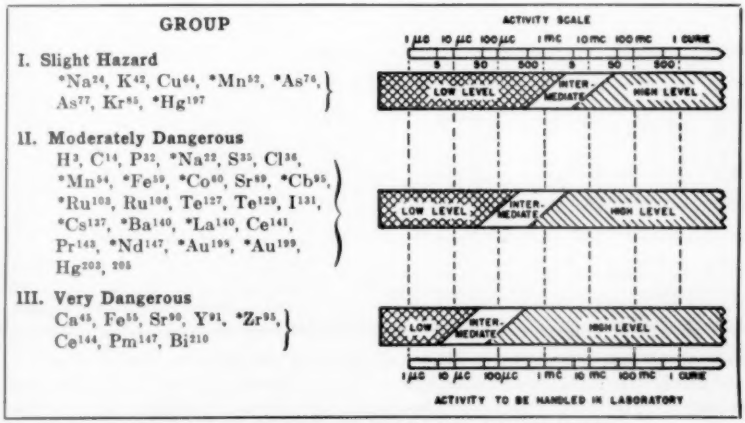
Isotopic exchange frequently takes place between different valence states of the same metal. Had it occurred in this investigation to any appreciable extent, it would have resulted in the presence of sizable quantities of both active trivalent and active hexavalent chromium in the plating bath, regardless of which was added. This would have made it impossible to draw any valid conclusions from the experiment. It was therefore necessary, before performing the experiment, to determine the extent to which isotopic exchange takes place between trivalent chromium and chromic acid in the plating bath.

Radiotoxicity Data Given For Principal Isotopes

Evaluating the hazards involved in handling radioisotopes requires a knowledge of the sites of deposition and elimination routes in the human body. Severe radiation hazard is associated with those isotopes that have an unfavorable combination of long half-life, high uptake, deposition in small organs or in bone, and low rates of elimination from the body.

The table on p. 88, adapted from the booklet "Safe Handling of Radioactive Isotopes" (prepared by the National Bureau of Standards and available for 15 cents from the Superintendent of Documents, Washington 25, D. C.), lists the radioisotopes most generally in use, with physical and metabolism data for each. Application of this data is indicated in the diagram (below), which groups selected radioisotopes according to relative radiotoxicity. Activities considered as low, intermediate, and high level in laboratory practice are also indicated.

In preparation of the figure, effective radiotoxicity was obtained from a


GROUP
I. Slight Hazard
*Na24, K42, Cu64, *Mn52, *As76, As77, Kr85, *Hg197
II. Moderately Dangerous
H3, C14, P32, *Na22, S35, Cl36, *Mn54, *Fe59, *Co60, Sr89, *Cb95, *Ru103, Ru106, Te127, Te129, I131, *Cs127, *Ba140, *La140, Ce141, Pr143, *Nd147, *Au195, *Au199, Hg203, 205
III. Very Dangerous
Ca45, Fe55, Sr90, Y91, *Zr95, Ce144, Pm147, Bi210
ACTIVITY SCALE
1 µC 10 µC 100 µC 1 mC 10 mC 100 mC 1 CURIE
5 50 500 5 50 500
LOW LEVEL
INTER-MEDIATE
HIGH LEVEL
ACTIVITY TO BE HANDLED IN LABORATORY

Hazard from absorption of radioisotopes into the body

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PROPERTIES OF THE PRINCIPAL RADIOISOTOPES

Isotope	Half-life	Energy (Mev)		Estimated quantities available (mc)	Principal uses
		Beta	Gamma		
H^3	31y	0.014	None	mc	Trace for H; auxiliary trace for C.
C^{14}	5,100y	0.154	"	mc	Labeled organic compounds.
Na^{24}	14.8h	1.4	1.4, 2.8	200	Tracer studies of Na metabolism; diagnostic tests.
P^{32}	14.3d	1.69	None	1,500	Therapy; diagnosis; P chemistry; $PO_4^{=}$ tracers.
S^{35}	87.1d	0.17	"	1.0	Tracer on sulfur drugs; analytical chemistry.
Cl^{36}	10^6y	0.66	"	0.005	Cl chemistry; tracer gas.
K^{42}	12.4h	75%: 3.58; 25%: 2.07	1.51 (25%)	130	Tracer study of K compounds.
Ca^{45} (a)	180d	0.25	None	1.0	Studies of Ca deposition; analytical chemistry; alloy studies.
Mn^{52}	6.5d	K, e+	0.56, 0.73, 1.46	100	Trace biology.
Mn^{54}	310d	K	0.835	1.0	
Fe^{55} (b)	4y	K	0.07	1.0	Tracer on Fe drugs; blood chemistry.
Fe^{59} (b)	44d	0.26, 0.46	1.1, 1.3	1.0	Fe chemistry.
Co^{60}	5.3y	0.3	1.1, 1.3	200	Trace biology; gamma source; Co chemistry; alloy studies.
Cu^{64}	12.8h	0.58β^-, 0.66β^+, K	1.2 (weak)	1.0	Trace biology; alloy studies; Cu chemistry.
As^{76} (c)	26.8h	1.1, 1.7, 2.7	0.57, 1.25	30	Tracer studies with arsenical drugs.
As^{77} (c)	40h	0.8	None	1.0	Alloy studies.
Sr^{89} (d)	55d	1.5	"	1,000	Sr chemistry.
Sr^{90} (d)	25y	0.65	"	mc	
Mo^{99}	6.7h	1.3	0.24, 0.75	.....	Plant growth; animal metabolism.
I^{130} (e)	12.6h	0.61, 1.03	0.42, 0.54, 0.67 0.74	250	Thyroid tracers; thyroid therapy.
I^{131} (e)	8d	0.6	0.367, 0.080	130	I chemistry.
Ba^{133}	12d	K, e−	1.2 (weak)	6.0	
Ba^{140}	12.8d	1.05	0.542	mc	Analytical chemistry.
Au^{198}	2.7d	0.97	0.44	80	Alloy studies.
Au^{199}	3.3d	1.01	0.45	10	Au chemistry.
Hg^{197}	64h	K, e−	0.075	100	Low-energy gamma source.
	25h	K, e−	0.13, 0.16		
$Hg^{203,205}$	51.5d	0.3	0.28	150	Alloy studies.
Bi^{210}	5d	1.17	None	10	Tracer studies of Bi drugs.

[a] Calcium absorption and excretion is dependent on blood calcium level.
[b] Iron absorption from the gut is influenced by the level of iron present in the blood and liver. Once iron enters into the metabolism of the animal, the excretion rate for that iron is very low.
[c] As: Retention in all tissue is very low.

weighting of: half-life, energy and character of radiations, degree of selective localization in the body, rates of elimination, and quantitites involved and modes of handling in typical experiments. The slant boundaries between activity levels indicate border-line zones; they emphasize that there is no

Metabolism								
Ingestion			Inhalation			Parenteral		
Absorbed	Deposition(f)	Eliminated	Absorbed	Deposition(f)	Eliminated	Absorbed	Deposition(f)	Eliminated
(g)	(g)	(g)	Same	Same	Same	Same	Same	Same
(g)	Bone: L	Lung	"	"	"	"	"	"
		Feces						
	(g)	Urine						
High	Body fluids: H	Urine	"	"	"	"	"	"
"	Bone: M	"	High	Bone: M	Urine	High	Bone: M	Urine
								Feces
(g)	Liver	"	Same	Same	Same	Same	Same	Same
	All protein							
High	Body fluids: H	"	"	"	"	"	"	"
"	Blood: H	"	"	"	"	"	"	"
	Muscle							
	Bone: H	Feces	"	"	"	"	"	"
		Urine						
		Feces	"	"	"	"	"	"
	Blood: H	"	"	"	"	"	"	"
	Bone(?)	Urine	"	"	"	"	Kidney	Urine
	Liver	Feces					Liver	
(g)	Liver: M	Urine	"	"	"	"	Same	Same
		Feces						
Low	Bone: M	Feces	"	Bone: M	Urine	(g)	Bone: M	Urine
	Hair: L	Urine		Hair: L			Hair: L	
	Bone: H	Feces	(g)	Bone: H	Feces	(g)	Bone: H	Feces
		Urine			Urine			Urine
	Bone: M	Feces						
High	Liver: M	Urine	Same	Same	Same	Same	Same	Same
	Kidney: M							
"	Thyroid: 20 %	Urine	"	"	"	"	"	"
	Bone marrow	Feces	"	"	"	"	"	"
	Liver: M	Feces	(g)	Liver: M	Urine	(g)	Liver: M	Urine
(g)		Urine						
(g)	Liver		Same	Same	Same	Same	Same	Same
	Kidney							
Low	Kidney	.....	.....	Low	"	"	"	"
	Liver							

[d] Sr: Absorption and deposition (5 to 80 percent in bone) vary with age and existing Ca level.
[e] Doses in excess of 0.1 gm give a low retention.
[f] H, L, and M indicate high, low, or moderate percentage of deposit out of total amount absorbed.
[g] Indicates chiefly dependent on compound.

sharp transition between the levels. Principal gamma emitters are indicated by an asterisk.

External radiation hazards are normally considered in terms of emitted gamma radiation. The activity level system given here does not apply for external hazards. END

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BOOKS

This I Do Believe, by David E. Lilienthal, Harper & Brothers, New York, 1949, 208 pages, $2.50. *Reviewed by Norman R. Beers, Editor,* NUCLEONICS.

This book contains many fine ideas, not a few of which will never provoke any comment unless and until sought out and "sold." Chairman David E. Lilienthal, U. S. AEC, recognizes the importance of selling when he says, for example, "In international affairs, at a stormy time in the world, the process of trying to 'sell' ideas has taken the center of the stage. . . . The American people are quite willing to buy soap or toothpaste because somebody else recommends them and they are attractively advertised. But, thus far at least, they don't 'buy' their economic or political opinions by such a process. As long as the American people make up their minds on important public questions, independently, by their own observations rather than by taking somebody else's word for it, as long as the Leader principle has no appeal, democracy is still in vigorous good health."

If provided with an extensive index and expounded by a second Will Rogers, whose posthumous autobiography has also just been published, the content of Lilienthal's credo would fill several times the present two hundred and eight pages; and the ideas in it would gain the wider audience any writer wishes to obtain. As it is written, however, "This I do Believe" presents too much in too small a space to assist the American people in making up their own minds on important public questions. The author seems to dispose of very important matters by implication. He has for example placed in italics the sentence from the Atomic Energy Act of 1946 which reads, "*Therefore, any legislation will necessarily be subject to revision from time to time.*" The reader is perhaps entitled to learn whether Lilienthal believes this legislation should now be changed; but nothing in the book under review indicates the author's belief whether or not it is time to change the Act.

Lilienthal notes that, "The creative powers of science stem directly from the ever-accelerating dissemination of information. . . . Scientific progress is actually measured (or measurable) by the amount of scientific knowledge abroad in the land." And later, "To try to bury or to suppress new knowledge because we do not know how to prevent its use for destructive or evil purposes is a pathetically futile gesture."

Perhaps the greatest attention should be directed to the author's proposal that, "Out of the best and most productive years of each man's life, he should carve a segment in which he puts his private career aside to serve his community and his country, and thereby to serve his children, his neighbors, his fellow-men, and the cause of freedom." Is this not done now by many? Was it not done by the millions in uniform in World War II for example? By the other millions frozen in a "war job"? *In fact,* is it not true that the private career which fails to be of service to the community and country is criminal or nonexistent? Whether the individual elects to make his "private career" in the public service of medicine, agriculture, banking, publishing, *etc.*, or aspires to one or many years of the author's Universal Public Service (which this reviewer infers to be synonymous with Government) is and will remain the choice of the individual in the Democracy served by Messrs. Washington, Jefferson, Lilienthal, you, and me.

Theory of Atomic Nucleus and Nuclear Energy Sources, By G. Gamow and C. L. Critchfield, Oxford Press, London, 1949, $9.00. *Reviewed by S. A. Goudsmit, Dept. of Physics, Brookhaven National Laboratory.*

This book is an excellent introduction to nuclear structure. It is especially refreshing because it does not adhere to the standard approach followed by most other authors when writing books and articles on the subject. The book also places particular emphasis on some of the subjects to which one of the authors has made significant contributions.

As the title of this edition indicates, special attention is given to nuclear energy sources, primarily in connection with cosmological problems. Typical examples of this are contained in the sections about the physical condition in stellar interiors, nuclear reactions in stars and ideas about the origin of the chemical elements.

Some of the references and data given in the book are not always accurate. For instance, on page 2, Prout is called a *French* chemist. However, taken as a whole, and if it is not primarily consulted for detailed information, the book is a most valuable and inspiring addition to the literature.

BOOKS RECEIVED

Elementary Modern Physics, by Gordon Ferrie Hull, The Macmillan Company, New York, 1949, 503 pages, $5.25. (This is an extensive revision of the author's earlier book "An Elementary Survey of Modern Physics.")

The Transuranium Elements (Div. IV, Vol. 14B, of National Nuclear Energy Series), by Glenn T. Seaborg, Joseph J. Katz, and Winston M. Manning, McGraw-Hill Book Co., Inc., New York, 1949, Parts I and II, 1,733 pages, $15.00.

Principles of A New Energy Mechanics, by Jakob Mandelker, Philosophical Library, New York, 1949, 73 pages, $3.75.

OTHER LITERATURE

Handling Radioactive Wastes in the Atomic Energy Program. This booklet describes radioactivity and its biological effects, the types and sources of radioactive wastes in the atomic energy program, and methods used for safe handling of wastes and protecting workers and the public from radioactive contamination. Reported also are details about the extensive research program currently supported by the U. S. Atomic Energy Commission to improve waste handling and storage methods. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 15 cents.*

Measurements of Radioactivity, National Bureau of Standards Circular 476. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., $1.25.*

The National Research Council Review, 1949. A description of the work of Canada's NRC, chiefly during year 1948, but with some notes regarding early work in 1949. It contains a roster of the scientific staff and indicates the general subjects under study. *N.R.C. No. 1997; available from National Research Council, Ottawa, 75 cents.*

International Control of Atomic Energy and the Prohibition of Atomic Weapons. Recommendations of the United Nations Atomic Energy Commission. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 25 cents.*

What You Should Know about The Atomic Bomb. A message for doctors from the Surgeon General. *Available from The Surgeon General, Department of the Army, Pentagon Building, Washington 25, D. C.*

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NUCLEONIC EVENTS

AEC NAMES CONTRACTORS FOR FOURTH U-235 PLANT

With construction already under way on K-29, the third in a series of gaseous diffusion units for production of uranium-235 in the Oak Ridge area, the Atomic Energy Commission has announced that the Maxon Construction Company, Inc., of Dayton, Ohio, had been approved as construction contractor and Giffels & Vallet, Inc., of Detroit, as architect-engineer for the building of a fourth gaseous diffusion unit, K-31. This new plant will cost approximately $162,000,000.

The Maxon Company and Giffels & Vallet already are engaged in the building of K-29, a $66,000,000 project. The Carbide and Carbon Chemicals Corporation, operator of the present gaseous diffusion units, K-25 and K-27, is responsible for process development and process design for both K-29 and K-31, and for procurement of special production equipment and materials.

The AEC said that with preliminary design work already accomplished, preliminary construction work is expected to begin shortly for K-31, which will be situated in the same general area as the other diffusion plants.

BROWN NAMED AEC DIRECTOR OF ENGINEERING

George G. Brown, chairman of the Department of Chemical and Metallurgical Engineering at the University of Michigan, has been named director of the Atomic Energy Commission's Division of Engineering, according to an announcement by Lawrence R. Hafstad, director of AEC's Division of Reactor Development. The position has been vacant since Roger Warner resigned last August 19.

Dr. Brown will be responsible for the chemical engineering phases of the AEC's reactor development program and will work under the general supervision of Dr. Hafstad.

"The growth of the reactor development program," Dr. Hafstad said, "focussing attention as it does on the chemical problems that have to be solved before nuclear energy can be utilized successfully, prompted appointment of a chemical engineer to this position."

AEC PERMITS PRODUCTION OF URANIUM FOR RESEARCH

Production of 200 pounds of uranium metal for use under Atomic Energy Commission license in non-AEC research projects in the United States has been authorized by the AEC, Wilbur E. Kelley, manager of AEC's New York Operations Office has announced.

The metal will be specially produced and fabricated in the form of rods by the Mallinckrodt Chemical Works, St. Louis, Missouri. It will be made available by Mallinckrodt through normal commercial chemical channels, The retail price will be about $50 per lb.

The uranium metal to be made available is highly refined by ordinary standards. However, it will not have the extreme purity required for nuclear reactors and certain specific types of atomic energy research.

In accordance with provisions of the Atomic Energy Act of 1946, an AEC

license will be required of all purchasers of this uranium metal. The AEC established licensing regulations to conserve source materials on March 31, 1947. Inquiries concerning the availability of uranium metal for research purposes should be directed to: Licensing Division, U. S. Atomic Energy Commission, New York Operations Office, P. O. Box 30, Ansonia Station, New York 23, N. Y.

BREEDER DESIGN COMPLETED, CONTRACTOR SELECTED

The nuclear design of the experimental breeder reactor to be built at the test station at Arco, Idaho, has been completed by the Argonne National Laboratory, according to an announcement by the Atomic Energy Commission. At the same time, it was announced that the Bechtel Corporation, San Francisco, Calif., will do the major construction work.

Architect-engineering design, being done by the Austin Company, Cleveland, O., is more than 90% complete.

The Bechtel Corp. will build the steel, brick and concrete reactor structure, as well as the control, ventilation, cooling and other auxiliary equipment. The reactor core, will be furnished by Argonne, where it is being built.

Total cost of the reactor is expected to be $3,500,000. The work to be performed by the Bechtel Corp. will total $2,500,000.

CANADIAN-PRODUCED ISOTOPES AVAILABLE TO U. S. WORKERS

Qualified American applicants can now obtain radioisotopes from Canada, according to an announcement by the Atomic Energy Commission.

"Radioisotopes produced in Canada will be especially useful to certain specialized research work," said Dr. Kenneth S. Pitzer, director of the AEC Division of Research, "since the Chalk River, Ontario, reactor makes possible the production of some radioactive materials in higher concentrations than are available under the U. S. distribution program. The use of radioisotopes in these highly concentrated forms is of very great value in certain types of research which are either impossible or very difficult when attempted with lower-activity material."

Applications for Canadian-produced isotopes may be made to the Isotopes Division, U. S. Atomic Energy Commission, P. O. Box E, Oak Ridge,

ABOUT THE COVER

RADIUM has many uses today. One of its principal applications in the nucleonics field is as a component of radium-beryllium neutron sources. The photograph shows a mixture of radium-barium bromide crystals being dissolved in quartz basins. This is one stage of the process of fractional crystallization of the radium. The inset shows a crucible which contains the pure end product. It has a beautiful, very bright, bluish glow. When this radium is tubed and aged, it is used, in addition to the Ra-Be sources, for medical purposes, in industry for the examination of welds and flaws in metals, and in radioluminous compounds. Photo from Canadian Radium & Uranium Corporation.

Tennessee. The Isotopes Division has been named the coordinating agency for the import of Canadian radioisotopes and will process all applications for the Canadian materials which originate in the United States.

Applications will be examined on the same basis as applications for domestically produced materials, and applicants will be required to meet all the safety and health standards that are in effect here.

COMPLETION OF REACTOR AT BROOKHAVEN DELAYED

Unforeseen technical difficulties in design, engineering and construction have delayed completion of the nuclear reactor at the Brookhaven National Laboratory, according to the Atomic Energy Commission. The new research reactor, originally scheduled for completion this past fall, is now not expected to start operation for several months.

"The major difficulties," said the AEC, "developed during testing of a new type air cooling system under simulated operating conditions. The tests revealed that the air duct work of the system as originally designed would not stand up under operating conditions, and important modifications in the design and construction of the cooling system are being made."

While alterations are being made on the cooling system, design and construction of other features of the pile, now 90% complete, are also being rechecked.

Re-examination of the design and construction details of the pile is being done by scientists and engineers from Brookhaven, the H. K. Ferguson Company, the engineering firm in charge of the reactor construction, and Babcock & Wilcox, consulting engineers. Staff members and consultants of the AEC are also engaged in this work.

The expense of reviewing the design, engineering and construction and of making the necessary modifications in the structure will increase the estimated cost of the reactor and associated equipment from $23,322,000 to $24,827,000.

The Brookhaven reactor is designed for use for research purposes, and is similar in type to the research reactor in operation at Oak Ridge National Laboratory. Both reactors operate with slow neutrons using natural uranium as fuel with a graphite moderator to slow down the neutrons.

The designed maximum power level of the new reactor will be 30,000 kilowatts compared to 2,000 kilowatts for the Oak Ridge reactor.

AEC APPROVES 10 BIOLOGY, MEDICINE RESEARCH PROJECTS

Ten research proposals in the field of biology and medicine have been approved for support by the Atomic Energy Commission, according to an announcement by Shields Warren, director of the AEC Division of Biology and Medicine.

The newly approved proposals are:

Medicine

University of Oregon Medical School (Dr. Frank B. Queen): *Evaluation of Body Content of Radium in Individuals With No Known Exposure.*

Army Medical Center, Washington, D. C. (Major G. M. McDonnel; Lt. Col. R. D. Maxwell, *et al*): *Antibiotic Therapy in the X-ray Irradiation Syndrome.*

Sloan-Kettering Institute (Dr. Rulon Rawson): *Physiological Effects of Irradiation in Patients Receiving Large Doses of Iodine-131.*

University of North Carolina (Dr. G. C. Kyker): *Tracer Studies and Irradiation in Dental Metabolism.*

Memorial Hospital, New York City (Dr. Helen Woodward; Dr. C. P. Rhoads): *Measurement on Effects of Irradiation on Bone and Bone Phosphatase Activity.*

University of Washington, Seattle (Drs. D. J

Hanahan; H. J. Daubon; R. Williams): *Synthesis of Carbon-14-Labeled Diethylstilbestrol and a Study of its Metabolism in the Body.*

Biology

Lankenau Hospital (Dr. Grace Medes): *Origin and Fate of Amino Acids in Plants and Animals.*

University of Wisconsin Institute for Enzyme Research (Dr. David E. Green): *Studies on the Cyclophorase System of Animal Tissues.*

University of Georgia (Dr. Henry W. Schoenborn): *The Production of Mutant Strains of Euglenoid Flagellates and their Use in the Study of Carbon Dioxide Fixation Processes.*

Fish and Wildlife Service—U. S. Department of Interior (Dr. Walter A. Chipman): *A Survey of the Accumulation of Radioactivity in Marine Invertebrate Animals.*

REACTOR SCHOOL SET UP AT OAK RIDGE

Advanced training in the field of reactor development will be given government and industrial scientists and engineers at the newly established Reactor Development Training School at the Oak Ridge National Laboratory, according to an announcement by the Atomic Energy Commission. The students will fall into three categories:

a. Engineers from industrial organizations who will remain on their companies' payrolls while attending the school.

b. Employees of other atomic energy laboratories or other government agencies detailed to Oak Ridge for training.

c. Recent college graduates hired by Oak Ridge National Laboratory who will be trained as regular employees and will be available for transfer to reactor groups throughout the atomic energy program.

Present plans call for about 60 students to be trained at one time, about 30 students in categories *a* and *b* and an additional 30 in category *c*. The school will operate continuously. All students will be required to have complete security investigation and clearance since the lectures and study material will be classified. Selection will be made by the AEC from qualified applicants on the basis of the need of the organization with which its applicant is affiliated for personnel trained in reactor development, the applicant's potential contribution to the AEC programs, and his academic record.

F. C. VonderLage, former director of the training division of the Oak Ridge National Laboratory, has been named the director of the new school.

J. LUNTZ NAMED MANAGING EDITOR OF "NUCLEONICS"

Jerome D. Luntz, assistant editor of NUCLEONICS, has been promoted to the position of managing editor, effective January 1.

Mr. Luntz holds a B. E. E. degree from the City College of New York. During the war, he did research and development work on electronic instrumentation at the Cleveland laboratory of the National Advisory Committee for Aeronautics. Prior to joining McGraw-Hill in 1947, he was a member of the staff of the Dept. of Electrical Engineering at the University of Minnesota.

Mr. Luntz is a member of the American Physical Society, the American Association for the Advancement of Science and the Institute of Radio Engineers.

NUCLEAR NEWSMAKERS

Lincoln R. Thiesmeyer, executive assistant to the director of Brookhaven National Laboratory, has resigned to become president of the Canadian Pulp and Paper Research Corp.

Charles Allen Thomas, executive vice president of Monsanto Chemical Co., St. Louis, Mo., has been elected chairman of the board of directors of the American Chemical Society. Dr. Thomas, onetime director of what is now Oak Ridge National Laboratory, succeeds Professor Roger Adams.

N. Howell Furman, professor of chemistry at Princeton University, has been chosen president-elect of the American Chemical Society. Dr. Furman, a prominent analytical chemist and AEC consultant, will head the society in 1951.

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PRODUCTS and MATERIALS

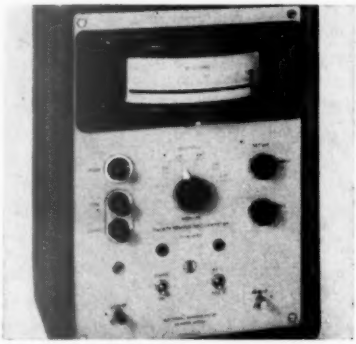
HAND AND FOOT MONITOR

Radio Corporation of America, Camden, N. J. Using dual-relay counting channels, for each measuring circuit, the type EMA-2B hand and foot monitor automatically compares subject and background count. A total of 12 G-M tubes, each with a separate supply voltage adjustment to obtain the middle of the tube plateau, is used to measure beta and gamma contamination of the front and back of each hand and the soles of the feet. Scales-of-eight for each hand channel and sixteen for the foot channel feed into relay counters. One set of relay counters is provided for storing background count; another set records the count for the subject. The monitor automatically compares the two, indicating their relationship by means of colored lights. Lights may be set to flash when hand channels indicate subject counts of four, eight, or, in multiples of eight, up to 240 times background. Foot channel lights may be set to flash when subject counts are, in multiples of 16, from 16 to 480 times background. In operation, the monitor is operated over one cycle (adjustable from 15 to 90 sec) to store up background count. Depression of the base plates of the acetate-lined hand boxes by the subject clears previous subject counts and starts a cycle. At the end of the cycle, the lights give an indication of extent of contamination. Actual counts may be read from the relays, which may be seen through the top of the separate control cabinet.

END-WINDOW COUNTER

Radiation Counter Laboratories, Inc., 1844 W. 21st St., Chicago 8, Ill. Using a quenching admixture of argon, xenon, oxygen, and nitrogen, the Mark 1,

Model 4X mica end-window counter is said to have an unlimited useful life. Sealed to the glass tube with a low-temperature polymerizing fusion seal, the two-inch diameter window has an equivalent thickness of less than 2 mg/cm². It is housed in a metal fitting to minimize breakage. Threshold voltage is approximately 1,600 volts. The tube has a 200-volt plateau with a slope of 3–8%/100 volts. A standard four-prong plug-in base is used.

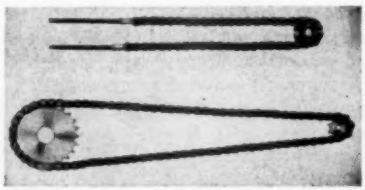


MEGOHMMETER

Herman H. Sticht Co., Inc., 27 Park Place, New York 7, N. Y. The model 29, 20-million megohmmeter, manufactured by Electronic Instruments, Ltd., Richmond, Surrey, England, is designed to measure electrical resistance over a range from 300,000 ohms to 20,000,000 megohms. This range is divided into six decades which are switch controlled. Resistance values are read on a six inch edgewise meter equipped with a mirror scale and knife-edge pointer. Operating from a 110 to 115 or 190 to 260 volt a-c supply, the instrument provides for test potentials of 85 and 500 volts d-c. A separate guard terminal is also provided. It is claimed that the test voltages provided by the meter's electronic circuit will not vary by more than 5 mv. The meter weighs 30 lbs.

PORTABLE ALPHA COUNTER

Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago, Ill. The model 2111 portable alpha proportional counter detects ouly alpha radiation in the presence of other radiation. A plug-in, four-tube integrating circuit is used to show the average count rate on a built-in meter. A push-button is provided for resetting the meter after exposure to a strong alpha source. Several types of probes are available, and earphones are supplied with the instrument. The plug-in circuit is easily removed for servicing; batteries are replaced through a hinged door on the end of the case. Weight of the complete instrument is 16 pounds.



MINIATURE CHAINS

Sierra Engineering Co., 123 E. Montecito Ave., Sierra Madre, Calif. Specifically designed for use around very small pulleys and sprockets, the miniature load-carrying chain and stud chain

are claimed to have noncorrosive and nonmagnetic qualities. Stainless steel chain is used for most applications; beryllium copper is available where nonmagnetic qualities are required. The load-carrying chain was developed to operate around pulleys as small as 3/16 inch in diameter and is capable of passing through a 180-degree turn without binding or slipping. Weighing 3/4 ounce per lineal foot, it has a yield strength of 310 pounds and an ultimate strength of 428 pounds when fabricated of stainless steel; when made of beryllium copper, it has yield and ultimate strengths of 290 and 440 pounds.

SURVEY METER

Radioactive Products, Inc., 3201 E. Woodbridge St., Detroit 7, Mich. The Raychronix model D-1 survey meter is an ionization-type, battery-operated instrument calibrated to measure beta and gamma radiation intensities over ranges of 0–50, 0–500, and 0–5,000 mr/hr. It is said to be accurate to within 10% of full scale in each range. The ion chamber, constructed of bakelite tubing, has a volume of approximately 600 cc. The 3-in. diameter, thin pliofilm window has a thickness equivalent to 1 mg per cm^2 and passes beta and gamma radiation with energies of 50 kev or greater.

ORE DETECTOR

Tracerlab, Inc., 130 High Street, Boston 10, Mass. Battery operated, the SU-7 ore detector uses earphones for auditory monitoring of Geiger tube pulses. The tube, which is contained in a probe at the end of a 30-inch cable, is small enough to permit exploration of small crevices and bore holes, but may be replaced with a larger tube if a higher counting rate is desired. The small tube has a background rate of about ten counts per min at sea level.

MONOCHROMATOR

The Perkin-Elmer Corp., Glenbrook, Conn. The model 83 monochromator can be used in the ultraviolet, visible, and infrared regions of the spectrum (18 to 40 microns). Optics are totally reflecting, and it is claimed that the

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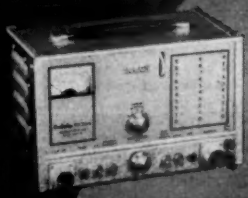

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Engineered for reliability and accuracy. Convenient to operate and service. Includes precision time clock. Decimal scale of 1000. Mechanical register. Electronically regulated power supply, 100 to 2500 volts. Automatic multiplier. Plug-in sub-assembly construction. Send for Bulletin BDS-204.

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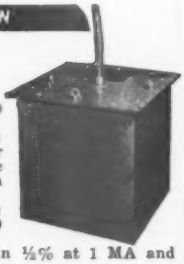
A compact, 0-100 KV power supply with reversible high voltage polarity was needed for the cathode supply of an electron or proton accelerator. (This supply has also been used for a Cyclotron beam deflector, for capacitor charging in high speed X-Ray studies and for Vacuum tube development work.)

SOLUTION



MAJOR SPECIFICATIONS:
Input: 117 Volts, 50/60 cycles, 200 Volt amperes
Output Voltage: 0-100 KV DC; either positive or negative high voltage with respect to ground
Output Current: Over 1 MA at 100 KV
Ripple: Less than ½% at 1 MA and 100 KV
Safety Features: Automatic output shorting mechanism when power is removed. Output control interlock for zero output at start. Provisions for external interlock: overload trip. at 1.5 MA
Size: High Voltage Tank 25" cube. Control Panel 19" x 12".

*M.I.T. (Cosmic Rays)
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National Research Council of Canada
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instrument can be focused with visible light for use in the other regions. Fourteen inches square and nine inches high, it is completely enclosed, with an entrance window before the entrance slit and a space thirteen by four inches behind the exit slit for mounting detectors. The collimator is an 18 degree off-axis parabola of 270 mm focal length, and the effective aperture of the Littrow mount is f/4.5. Glass, quartz, LiF, CaF_2, NaCl, KBr and KRS-5 prisms are available.

TUBING

Babcock & Wilcox Tube Co., Beaver Falls, Pa. Croloy (chromium-nickel-molybdenum austenitic stainless steel) tubing has been developed which, it is claimed, can be used for operations at 10,300 psi at 1,000° F. With an outside diameter of $4^{25}/_{32}$ in., the tubing has walls which are 1.169 in. thick.

INDUSTRIAL RADIOGRAPHY

St. John X-ray Laboratory, Califon, N. J. has designated an entire building for industrial radiography with cobalt-60. The company, which recently received a 350 mc source of Co^{60}, states that it is ready to apply this isotope on any field job.

SPEEDOMAX RECORDER

Leeds and Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa. Using d-c electronic circuits to control both pen and strip chart movement, this recorder automatically plots the relationship between two variables, showing one as a function of the other. Response is claimed to be amply fast: the pen takes three seconds for full horizontal scale travel of 9⅞ in., while full chart travel of ten in. requires four seconds. The chart paper drive, under electronic

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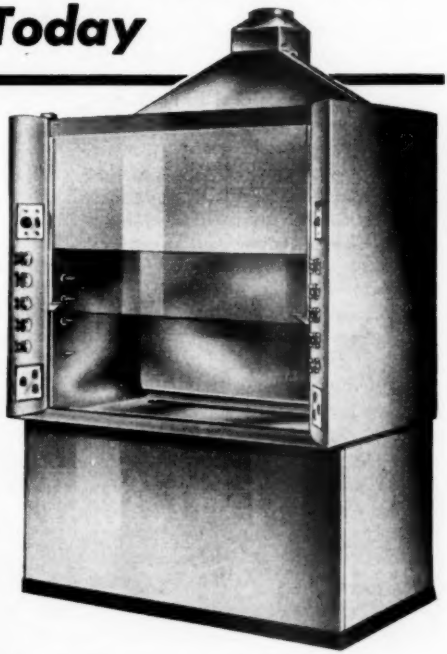

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control, is reversible. Full-scale pen deflection requires 2.5 millivolts. Ten millivolts is required for full travel of the chart.

THERMOSETTING CEMENT

Electro Chemical Supply & Engineering Co., 750 Broad St., Emmaus, Pa. Lecite, a new thermosetting synthetic resin cement, is claimed to be inert to solvents, fats, oils, greases, alkalis and acids, except strong chromic, nitric, and sulfuric acids over 60° Bé at temperatures to 375° F. Setting quickly to form a dense shiny shock-resistant joint, it has a compression strength in excess of 10,000 pounds per square inch. It will not foam to form a porous mortar and give off toxic fumes. The cement is noninflammable and may be stored indefinitely at atmospheric temperatures.

LITERATURE AVAILABLE

Data Concerning Platinum. Laboratory ware is cataloged, tables of physical constants and conversion factors applicable to platinum are given, and other company literature about platinum plating solutions, catalysts, resistance furnaces, and materials are briefly discussed. *Baker & Co., Inc., 113 Astor St., Newark 5, N. J.*

Hermetic Seals. Fused glass and metal terminals, terminal headers, crystal holders and other products are detailed. *Hermetic Seal Products Co., 29–37 S. Sixth St., Newark 7, N. J.*

Consolidated Recording Oscillographs. Multichannel galvanometer-type recording oscillographs are described in this 16-page bulletin. *Consolidated Engineering Corp., 620 N. Lake Ave. Pasadena 4, Calif.*

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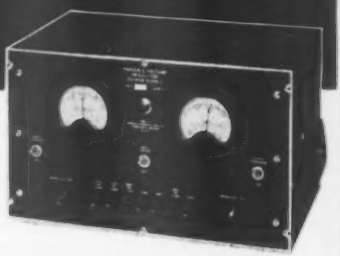

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